6-1-2016

Internal curing of high performance concrete using lightweight and recycled aggregates

Mohamed Afifi

Follow this and additional works at: https://fount.aucegypt.edu/etds

Recommended Citation

APA Citation
Afifi, M. (2016).*Internal curing of high performance concrete using lightweight and recycled aggregates* [Master's thesis, the American University in Cairo]. AUC Knowledge Fountain.
https://fount.aucegypt.edu/etds/247

MLA Citation
Afifi, Mohamed. *Internal curing of high performance concrete using lightweight and recycled aggregates*. 2016. American University in Cairo, Master's thesis. *AUC Knowledge Fountain*.
https://fount.aucegypt.edu/etds/247

The American University in Cairo

The School of Sciences and Engineering

INTERNAL CURING OF HIGH PERFORMANCE CONCRETE USING LIGHTWEIGHT AND RECYCLED AGGREGATES

A Thesis Submitted to

The Department of Construction Engineering

In partial fulfillment of the requirements for the degree of

Masters of Science in Construction Engineering

By

Mohamed Sameer Afifi

B.Sc. in Construction Engineering, 2013

The American University in Cairo

Under the supervision of

Dr. Mohamed Nagib Abou-Zeid

Dean of The School of Sciences and Engineering

Professor, The Department of Construction Engineering

The American University in Cairo

April 2016

DEDICATION

This thesis work is dedicated to my wife, Reem, who has been a constant source of support and encouragement during the challenges of graduate school and life. This thesis is just the beginning.

This thesis is also dedicated to Hany Abdel Rahman, my 4th grade teacher who passed away in March 2013. May your soul rest in peace. Thanks for everything you taught me.

ACKNOWLEDGEMENTS

ABSTRACT

Concrete curing is of paramount importance in order for concrete to meet performance requirements. Conventionally, curing has been conducted by means of water sparkling, wet burlap or a curing compound. For performance and environmental reasons, internal curing has been gaining increased attention. However, more data is needed for the effectiveness of this curing technique when used in various concrete mixtures.

This investigation addresses potential utilization of internal curing in high performance concrete (HPC). Internal curing was introduced by means of three aggregates: perlite, pumice and recycled aggregates; all of which were incorporated into HPC mixtures. Conventional mixtures were prepared and were thoroughly cured either by water or by a curing compound or left non-cured. Fresh concrete and Hardened concrete properties were assessed including slump, unit weight, compressive and flexural strength, and durability tests as shrinkage assessment, rapid chloride permeability test (RCPT) and abrasion resistance. Experimental work is backed up with a simplified feasibility analysis with case study, incorporating initial and future costs to better judge potential of this technique.

The outcome of this study uncovers that the addition of pre-wetted lightweight aggregates can prompt an enhancement in concrete workability and durability accompanied by a reduced shrinkage. Compressive and flexural strengths decreased with the increased replacement dosages, however several dosages were tested to reach a figure of optimum replacement. Results of this study reveal the potential of this technology in saving fresh water as well as the costs saved in maintenance and rehabilitation works.

Keywords: (Internal, Curing, High Performance, Concrete, Perlite, Recycled, Pumice)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

After placing and finishing of concrete, maintaining adequate moisture and temperature is of paramount importance; this happens through a process referred to as Curing. Appropriate curing of concrete structures is vital to assure they meet their anticipated performance and durability requirements (Kovler and Mejhade, 2007) (NPCA, 2013) (Babcock and Taylor, 2015) (Joseph, 2016) … to name only some. Proper curing entails creating the optimum environment to promote the hardening or hydration of freshly cast concrete (NPCA, 2013). The American concrete Institute (ACI) defines curing as the process by which hydraulic-cement concrete matures and develops hardened properties as a result of continued hydration of the cement in the presence of adequate water and heat (ACI 308R-01, 2015). Hence, an incomplete hydration process will affect both the strength and durability of produced concrete. Historically known for its importance, curing has a strong influence on hardened concrete; adequate curing will aid achieving desired durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicers (ACI 308R-01, 2015). Also, defined as maintaining satisfactory moisture content in concrete during its early stages in order to develop the desired properties (Joseph, 2016).

Water loss, during or after concrete finishing (i.e. evaporation), may delay or prevent sufficient hydration. The achievement of maximum strength is dependent on the extent of cement hydration and with proper curing, cement can more fully hydrate and achieve maximum strength (Bediako et al., 2015). Figure 1-1 is a classical demonstration

of the effect of different curing periods on strength gain; it improves quickly at early ages, and then continues slowly for an indefinite period (Gonnerman & Shuman, 1928).

There is an additional aspect of curing, which is sometimes overlooked. Curing is carried out not only to promote hydration, but also to minimize shrinkage (Kovler and Mejhade, 2007). Water loss will cause the concrete to shrink introducing tensile stresses that may cause surface cracking. In High performance concrete (HPC); concrete with high cement content and low w/c ratio, a major concern is self-desiccation, which is internal drying of concrete due to the consumption of water by hydration (Neville 1996; Parrot 1986; Patel et al. 1988, Spears 1983). Self desiccation results in hindered strength development, reduced durability and potential for autogenous shrinkage and cracking (Weiss et al., 2010). Historical records prove that if no sufficient water is provided, the paste can self-desiccate preventing concrete from achieving targeted properties. Appropriate mitigation methods to reduce shrinkage in combination with careful curing practices should be used to minimize and control shrinkage (Huo and Wong 2000).
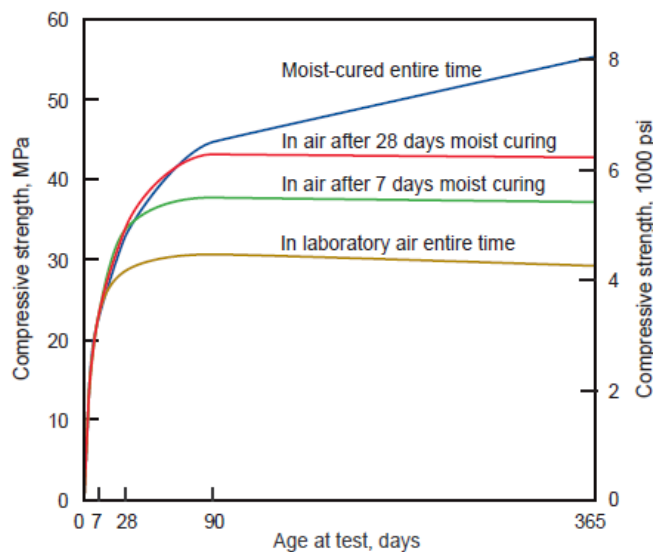
Figure 1-1: Effect of Curing time on concrete strength gain (Gonnerman & Shuman, 1928)

There are various techniques for curing; external & Internal Curing. Most of the traditional methods are based on external curing. Generally, external curing can be grouped as follows (Aitcin, 1998):

- Water Adding Curing – by supplying additional moisture to prevent/compensate water loss. This is achieved by water ponding, water spraying/sparkling, or by water coverings such as wet burlap. As shown in Figure 1-2 (Foster Supply, 2012)

- Sealed curing – by preventing the loss of moisture. This is achieved by Waterproof paper, plastic sheeting, and membrane forming compounds (also known as curing compounds). Shown in Figure 1-3 (Suryakanta, 2014).

Figure 1-2: Water adding curing methods: water spraying (left) - wet burlap (right) (Foster Supply, 2012)

Figure 1-3: Sealed curing plastic sheeting (left) - curing compound (right) (Suryakanta, 2014)

Internal curing is another concept of curing concrete, which is basically incorporation of a component that serves as curing agent to the concrete mixture. As defined by ACI, process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water (ACI 213-03R, 2012). Internal curing can be classified as follows:

- Internal Water Curing – embedded component is a water reservoir that gradually releases water into the system. The most popular methods are pre-wetted light weight aggregates and super absorbent polymers (SAP).
- Internal Sealing – component is meant to delay or prevent water loss from the system by adding special types of chemicals to mixing water (Kovler and Mejhade, 2007)

Internal curing proved to be promising in producing concrete with increased resistance to early-age cracking and enhanced durability (Bentz and Weiss, 2011). This is due to the enhanced curing reach inside the concrete section as illustrated in Figure 1-4,

4

conventional external curing provides curing mainly to outer concrete surface whereas in internal curing, water is simultaneously distributed inside of concrete and hence provide more uniform and extended curing of concrete (Abou-Zeid, 2015)
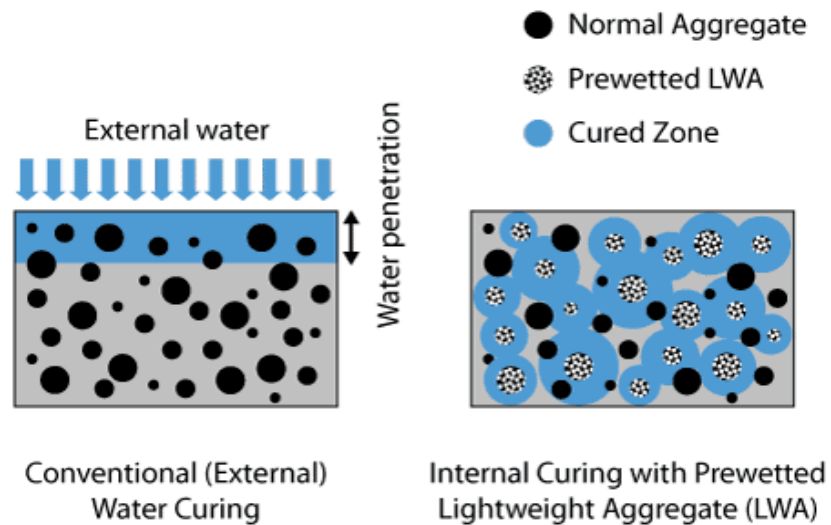
Figure 1-4:Illustration of the difference between external & internal curing (Weiss et al., 2012)

1.2 HIGHLIGHTS ON EGYPT'S INFRASTRUTURE BOOM

After the long period of projects recession that Egypt has experienced over the period of 2011-2014, the Egyptian economy is expected to recover after the resolution of the political instability. This rise up is coupled with a huge backlog in many projects. Needless to say, infrastructure projects, represented in bridges, roads, tunnels, power plants and water structures (water/waste water treatment plants), are expected to boom in a very short period. Earlier in 2015, the state announced investment budget of $40Bn over the period of 2015-2018 dedicated for series of construction and repairs infrastructure projects which was announced during the Egyptian Economic Development Conference (EEDC) held in Sharm El Sheikh, March 2015. Egypt

infrastructure projects are expected to consume average of 7.5Mm^3 annually of Ready mix concrete over the next 3 years (Market Studies, 2015). Being the third worldwide in road accidents with 12,000 deaths/year (WHO, 2013), Egypt has launched the National roads project to construct 4,000 km in coming 3 years with total investment of $4.6Bn (World Bank, 2016). Also, Egypt has introduced concrete roads for the first time, Khashm Al Rakaba main road, 200 km^{3}of paving over 1 year period (GARBLT, 2015). In the bridges sector, Egypt state has announced $450M budget for 15 bridges, along with 5 years maintenance program for 1100 bridge across Egypt (youm7, 2015). With the growing population and the hindered infrastructure the demand continues for transport, power and water projects. This project boom and the ambition to phase lift the infrastructure in a relatively short time should not compromise safety, durability or feasibility. Adapting advanced construction methods along with innovative construction materials and of course high-tech equipment may solve the knot.

Figure 1-5: Pictures shows the current case of Egypt's Infrastructure, collapsed bridge in Qalyobiya (left) and deteriorated road (right) (Alwafd, 2016)

1.3   RESEARCH MOTIVATION

This study is of crucial importance particularly in these days of Egyptian economical rise up. As discussed in section 1.2, the infrastructure boom will increase the need for high productivity and high performing structures without compromising durability or feasibility. In addition to Egypt's water scarcity challenge, makes it very important to use resources wisely. Two main aspects have the major contribution behind this study: (1) Egypt's need for durable structures for its strategic projects, and (2) Feasibility and Environmental aspects that should be carefully studied and adapted.

1.4   RESEARCH OBJECTIVES AND SCOPE

This investigation aims at exploring the influence of internal curing on the properties of high performance concrete. This is followed by a desire to transfer internal curing from research and lab to field experience. This work is dedicated to promoting the application of internal concrete curing in high performance concrete structures in Egypt (mainly infrastructure projects) and study economic and environmental aspects related. Detailed objectives of this work are:

1. Investigate the development, manufacture, and performance aspects of internal concrete curing.

2. Evaluate the benefits of internal curing by examining short term and long term properties and comparing it to conventional ways.

3. Develop preliminary feasibility model evaluating economical aspects of implementing such technology incorporating short and long-term related costs. A case study to be implemented to validate feasibility outcomes.

4. Analyze environmental aspects of the technology and impact on Egypt resources.

1.5 RESEARCH METHODOLOGY

The approach employed in this study to achieve the above mentioned objectives is:

1. Conduct an extensive literature review on internal concrete curing, its history and development, theory, proportioning, properties, production and applications

2. Perform standard materials testing to examine fresh and hardened properties of concrete produced through internal curing and compare it to conventionally cured concrete. Results are listed, compared and interpreted to fully understand this new technology

3. Execute a simple feasibility study to analyze economic and environmental features of applying this technology in Egypt. All related aspect of construction and life cycle cost should be taken in consideration for a comprehensive model.

4. Propose set of recommendations and guidelines for applicators in Egypt for a smooth technology transfer to allow internal curing to be developed, specified, produced and implemented in Egypt.

1.6 ORGANIZATION OF CHAPTERS

This study will consist of five other chapters outlined as follows:

Chapter 2: Presents a literature review regarding the internal concrete curing discussing history and development, theory, proportioning, mechanical properties, production aspects and application. A review on recent papers and studies are performed to achieve comprehensive perspective on the technology.

Chapter 3: Introduces the methodology of evaluation of the internal concrete curing. This chapter will discuss materials used and corresponding properties. Mixture

proportioning and mixing procedure will be illustrated in detail. Also, Experimental methods, testing standards and purposes of each test shall be addressed.

Chapter 4: Displays the results of the fresh, hardened and durability testing of the concrete specimens. Internal concrete curing results should be listed and compared to the conventionally cured concrete, to better understand properties of this new technology. Results will also be explained and interpreted to identify behavior and reasons of occurrence.

Chapter 5: Executes a simplified feasibility analysis of applying internal concrete curing in Egypt. Taking in consideration materials, production and application costs, as initial costs of the system. Life cycle cost analysis based on serviceability of structures will also be evaluated to be able to correctly judge the feasibility of this technology. Environmental aspects of water will also be discussed. A case study is discussed to validate and further emphasize on the benefits.

Chapter 6: Offers conclusions to the whole study. Conclusions are drawn from experimental and feasibility results obtained from chapters 4 and 5. A set of recommendations to industry applicators are highlighted for smooth implementation of the technology. The importance for future research and work continuation is highly emphasized.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In the 21st century, internal curing has developed as a new innovation that holds guarantee for delivering concrete with enhanced resistance to early-age cracking and improved durability (Bentz and Weiss, 2011). Since concrete service life is a key part of developing practical infrastructure, internal curing can positively impact the sustainability of Egypt's infrastructure. The American Concrete Institute (ACI) defined internal curing in its ACI Terminology Guide as "supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation" (ACI 308R-01, 2015). This definition defines the two noteworthy goals of internal curing; boosting hydration and minimizing self-desiccation, along with stresses that may create early-age cracking (Bentz and Weiss, 2011). The main objective of this chapter is to give a wide perspective on the internal curing technology taking in consideration previous developments and researches. This review was expedited with information from assembled papers that discussed development, theory, mixture proportioning, and applications of internal curing.

2.2 HISTORY AND DEVELOPMENT

History of natural lightweight aggregates dates back to the Roman times, in the famous Pantheon in Rome; "The dome of the Pantheon was constructed using a lightweight concrete with natural vesicular aggregates, where the density of the concrete was reduced as its height within the dome increased (Bremner & Ries, 2009). In 1918

Stephen J. Hayde started the production and development of artificial lightweight aggregates from clay, shale, and slate rocks (Bremner & Ries, 2009). Hayed's innovation was used to produce concrete ships for world wars I &II. Interestingly, many of these concrete ships are still floating till now, which gives an indication of the high durability of lightweight concrete (Holm, Bremner, & Newman, 1984), however, nothing about internal curing was revealed.

Paul Klieger was the first to highlight the curing capabilities of lightweight aggregates in 1957, he wrote "lightweight aggregates absorb considerable water during mixing which apparently can transfer to the paste during hydration" (Klieger, 1957). Few years later, specifically in 1991, concrete technologist Robert Philleo whose research interests are in high strength concrete wrote "Either the basic nature of Portland cement must be changed so that self-desiccation is reduced, or a way must be found to get curing water into the interior of high-strength structural members" (Philleo, 1991). Researches and investigations on internal concrete curing using pre-wetted lightweight aggregates continued through "a variety of research groups in Germany (Weber & Reinhardt, 1995), the Netherlands (van Breugel & de Vries, 1998), and Israel (Bentur, Igarishi, & Kovler, 1999) (Bentz and Weiss, 2011). Likewise with numerous new advancements, the way from research and examination to practice has been a moderate one, however starting 2010, a huge number of cubic meters of concrete containing pre-wetted LWA for internal curing have been effectively set all through the U.S. (Villareal, 2008).

2.3 THEORY

"So if we add 1 + 1 we have 1.8!" Said professor Jason Weiss commenting on cement hydration (Weiss, 2011). In this manner, the hydration reactions are joined by a net chemical shrinkage as the items involve less space than the reactants (Bentz and Weiss, 2011). Then again, after a cement paste sets and builds up a limited resistance to deformation, the chemical shrinkage, without extra water, will develop self-desiccation, as incompletely filled pores will be made inside of the microstructure (Lura, Couch, Jensen, & Weiss, 2009). Young's Equation (Alberty & Daniels, 1980) best describes the relationship between the capillary pressure in the system (σ), the surface tension of the fluid in pores (γ), contact angle (θ) and the pore radius (r), equation (1) below shows the formula:

$$\sigma = \frac{(-2\gamma\cos\theta)}{r}$$

[Equation1]

from equation (1), it is obvious that to decrease the capillary pressure, either reduce the surface tension of the fluid in pores by using shrinkage-reducing admixture (Shah, Weiss, & Yang, 1998) (Bentz, Geiker, & Hansen, 2001), or by increasing the pore size by incorporating water reservoirs inside the larger pores (internal curing) (Bentz and Weiss, 2011).

As the water inside the pore start to empty for the hydration process to continue, capillary pressure increases, as a result a measurable shrinkage of the system could be

12

produced. The strain cause by the capillary pressure is described by the Mackenzie's equation below:

$$\varepsilon = \frac{\sigma S}{3}\left[\left(\frac{1}{K}\right) - \left(\frac{1}{Ks}\right)\right]$$

[Equation 2]

where the linear strain (ε) is directly proportional to the capillary pressure. S, K and K_s are the saturation in pores (0-1), bulk modulus of porous material, bulk modulus of solid backbone, respectively (Bentz and Weiss, 2011). At the point when these autogenous stresses and strains get to be enough, they may add to, or independently cause, early-age cracking that will sacrifice the expected design and service life of a concrete structure by giving open pathways to the ingress of unwanted materials.

Taking into account the above investigation, the goal of internal curing is to give a source of promptly accessible extra water so that the hydrating cement paste stays saturated, and consequently minimizing the autogenous stresses and strains. This extra water will likewise advance hydration of the cement in the blend. Traditionally, some of this extra water has been given by external curing systems, for example, ponding, hazing, moistening, and the utilization of wet burlap. On the other hand, in the higher performance concretes that are currently being utilized, the fine porosity gets to be separated in the first couple of days of hydration (Powers, Copeland, & Mann, 1959), such that this outer water might just penetrate a couple of millimeters into the concrete from the curing-applied surfaces (Bentz, 2002), while the inside of the concrete experiences self-desiccation. The objective of internal curing is to give extra water in the best possible sum and with a fitting spatial distribution so that the

13

whole three-dimensional microstructure of hydrating cement paste stays moist and autogenous stress free. (Bentz and Weiss, 2011)

2.4 PRACTICE: MIX PPROPORTIONING

Mix proportioning with internal curing gives the fundamental extra water to extend time of saturated conditions in the hydrating cement paste. The upkeep of these saturated conditions will both add to the accomplished level of reaction of the cement, furthermore minimize the advancement of autogenous stresses and strains that cause early-age cracking. Three key inquiries to consider in this outline procedure are accordingly: 1) How much internal curing water is required for a given arrangement of mixture contents, 2) How far from the surfaces of the internal reservoirs into the cement paste can the water travel, and 3) How are the internal stores dispersed inside of the mortar's structure or concrete sample? (Bentz and Weiss, 2011).

To answer the first question of how much water is needed, a simple logic is used. Equation (3) is developed to predict the mass/volume of required internal reservoirs, by equating the water demand of the hydrating mixture to the supply that is available from the internal reservoirs.

$$C_f \times C_s \times \alpha_{max} = S \times \emptyset_{LWA} \times M_{LWA}$$

[Equation 3]

In this form of the equation, the left side represents the water demand through the cement content (C_f), the chemical shrinkage of the binder at 100% saturation (C_s) – approximately equals 0.07 mL/g cement for Portland cement, and the expected degree of reaction of the cement (α_{max}). The right side represents the water supplied by internal

14

curing through pre-wetted aggregates. Water supply is represented through the mass of lightweight aggregates (M_{LWA}), the saturation level (S) - equals 1 for w/c of 0.36, and the absorption capacity of the aggregates (Φ_{LWA}) (Bentz, Lura, & Roberts, 2005). This same approach could be employed when using crushed returned concrete aggregates as the internal curing reservoirs (Kim & Bentz, 2008). When equation (3) is used to figure the required amount of LWA, the last substitution of normal weight aggregates (NWAs) by LWAs ought to be performed on a volume premise, because of their critical contrasts in density (Bentz, Lura, & Roberts, 2005).

It is very important to replace NWA with LWA of similar or close sizes and keep the final overall gradation to produce quality concrete (Villarreal & Crocker, 2007). One last issue to address concerning mix proportioning for internal curing is the potential for either "undercuring" or "overcuring". Undercuring can happen when the water gave by internal curing is not as much as that prescribed by equation (3) and just keeps up saturated conditions for some limited timeframe, when a portion of the internal curing water is uprooted by surface dissipation, or when the internal curing water is not adequately all around appropriated all through the three-dimensional microstructure. Overcuring may possibly happen when water ponding or wet burlap is utilized to give outer curing to a concrete proportioned with internal curing (Cusson & Hoogeveen, 2008). At the point when a concrete is proportioned for internal curing as per equation (3), all the needed water is incorporated in the internal reservoirs. If that extra water is given at the concrete's surface, a water's segment in the internal reservoirs may remain in place instead of moving to the hydrating cement paste. In the event that such specimens were presented to freezing conditions before this water has had an opportunity to move

out of the internal stores, its durability may be compromised. At the point when internal curing is proportioned for a concrete mixture taking after the methodology of equation (3), external curing is best used to seal up the outside surfaces so that the internal curing water will stay inside of the concrete to fill its proposed needs (Bentz and Weiss, 2011).

Knowing how much water is required for internal curing, the last issue that should be comprehended is the circulation of the LWA all through the microstructure. Regardless of the fact that an adequate volume of water is supplied to a system, if the water is inadequately distributed, the system will probably display poor shrinkage performance. This has been concluded by looking at the adequacy of coarse LWA and fine LWA when the same volume of water is considered (van Breugel and Lura, 2000; Zhutovsky et al. 2002). Despite the fact that the volume of water may be the same, the distribution of the LWA particles will be entirely different, bringing about an alternate volume of secured paste (i.e., the volume division of the paste inside of a given separation from a LWA molecule).

The coarse LWA ended up being less effective than the fine LWA despite the fact that they had the same volume of water, clear distinction can be made in the secured paste volume in these two figures. Due to the better particle distribution, the fine total can possibly ensure the encompassing cement paste than coarse total. Utilizing fine aggregates rather than coarse aggregates could have implications on strength. Replacing the coarse typical weight aggregate with coarse LWA could have inconvenient consequences for the quality of the concrete. At the point when managing higher quality concretes, the aggregate particles will probably be the point of failure, and bringing weak particles into the system could decrease the quality. By replacing the fine typical weight

aggregates with fine LWA, the impacts if including a weaker total could be eliminated knowing that the fine aggregates do not influence the concrete's quality as much as the coarse aggregates (Weiss et al., 2010)
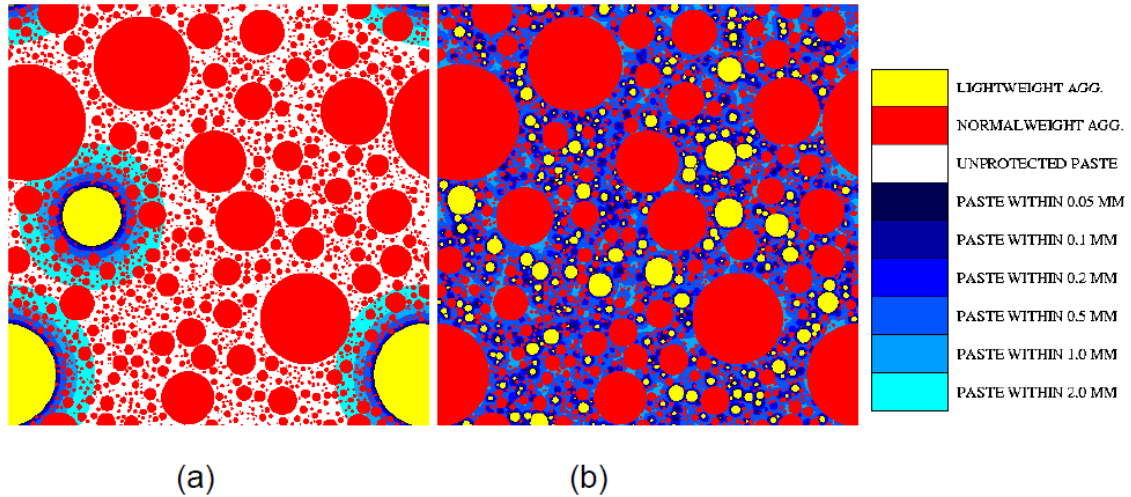
Figure 2-1: Illustrations showing the protected paste volume of two mixtures with similar LWA replacements of (a) coarse aggregate, and (b) fine aggregate (Henkensiefken, 2008)

2.5 LAB STUDIES

It is of crucial importance to study past lab studies to understand how mechanical properties are affected by replacing normal weight aggregates by lightweight aggregates. This section shall conclude past experiences of LWA replacement on plastic shrinkage, autogenous shrinkage & relative humidity, strength, elastic modulus, curling & wrapping, and transport coefficients, and service life.

2.5.1 PLASTIC SHRINKAGE

Concrete can crack at the placement time if the dissipation rate is high (Villarreal and Crocker, 2007). While these cracks are not by large a reason for worry as far as the load

the structure can carry, they are unwanted and can prompt the ingress of undesired elements that could expedite the corrosion of the reinforcing steel. Studies have been recently directed to look at the plastic shrinkage and cracking tendencies of concretes with and without internal curing (Henkensiefken, Briatka, Bentz, Nantung, and Weiss, 2010). To assess their potential for plastic shrinkage cracking, examples were tried after ASTM C1579 "Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)" (Lamond, and Pielert, 2006). Lab studies conclude that in plastic shrinkage cracks are heavily reduced with higher replacements of lightweight aggregates. This is mainly because the water in the LWA compensates for water lost by evaporation or bleeding. Figure 2-2 shows crack width versus probability of cracking for different replacements of LWA. (Henkensiefken, Briatka, Bentz, Nantung, & Weiss, 2010).
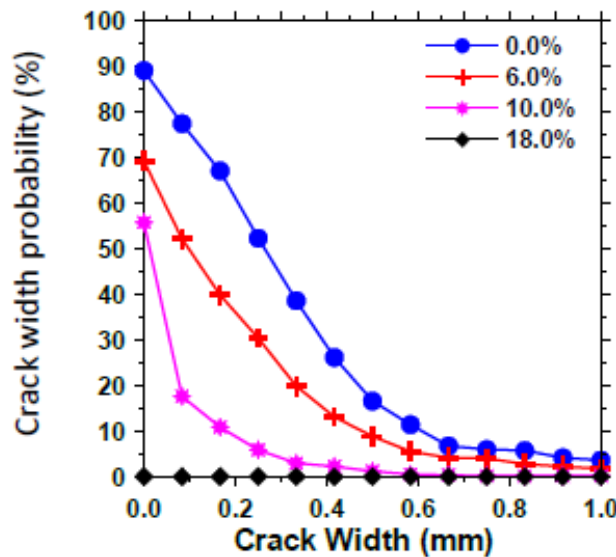
Figure 2-2: Probability distribution of crack width occurrences in concrete with different replacement volumes of Pre-wetted LWA (Henkensiefken, Briatka, Bentz, Nantung, & Weiss, 2010)

18

It is obvious that the use of pre-wetted lightweight aggregates greatly reduces both plastic shrinkage potential and crack width through compensating moisture lost in the system. However, it is worth notching that any water lost at this stage will not be available to reduce autogenous shrinkage that may cause self-desiccation.

2.5.2 AUTOGENOUS SHRINKAGE & RELATIVE HUMIDITY

Since one of the real targets of adding internal curing into a concrete blend is to lessen autogenous shrinkage and the cracking that may go with it, various studies have given estimations of autogenous deformation in concretes with and without internal curing (Kovler and Mejhade, 2007). All the more as of late, mortars with different replacement levels of pre-wetted LWA have been assessed for an assortment of early-age properties, including internal relative humidity and autogenous deformation (Henkensiefken, Bentz, Nantung, and Weiss, 2009). In that study, mortars with a w/c=0.3 were readied with replacement levels of LWA underneath. Figure 2-3 gives the deliberate internal relative humidity and autogenous deformations for the mortars with eight unique levels of internal curing. The outcomes show the normal movement in execution, as the internal relative humidity increments with expanding replacement level of LWA, while the autogenous shrinkage simultaneously diminishes.
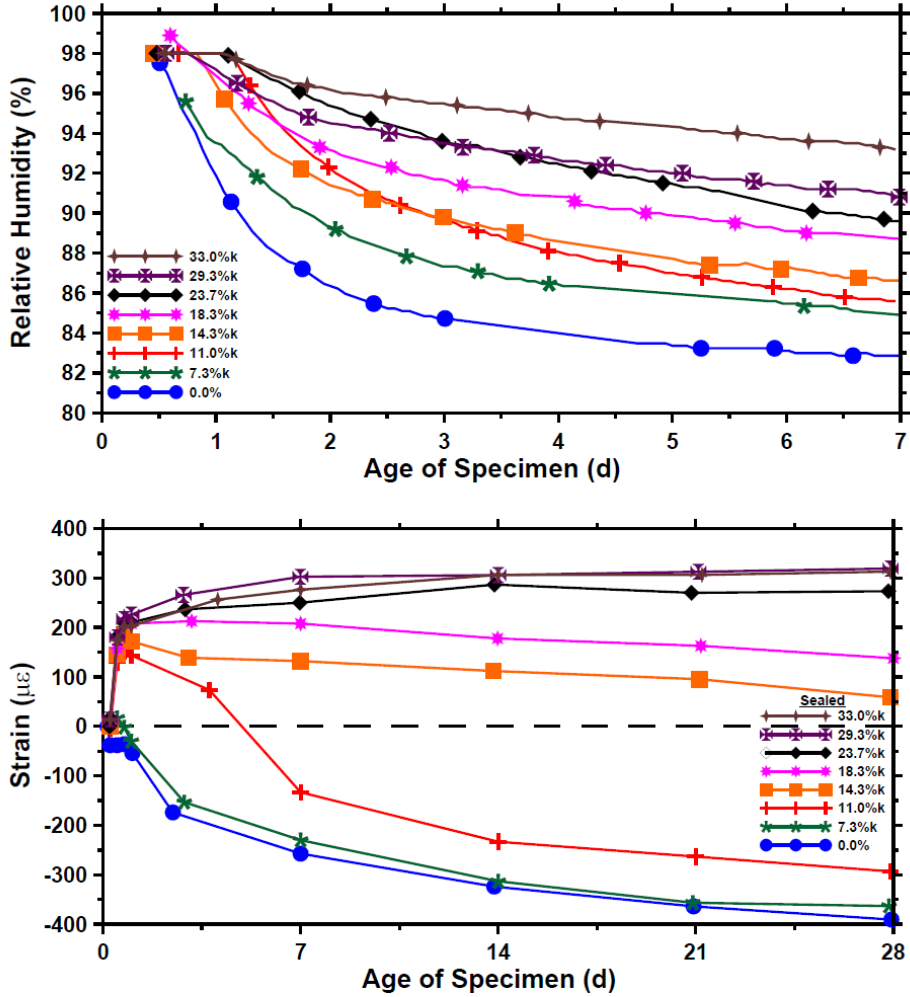
Figure 2-3: Internal relative humidity (top) and autogenous deformation measurements (bottom) with various levels of pre-wetted LWA replacement (Henkensiefken, Bentz, Nantung, & Weiss, 2009).

Utilizing the ASTM C1581 restrained ring shrinkage test it was exhibited that the decrease in autogenous shrinkage undoubtedly brought about a lessening in cracking as appeared in Figure 2-4 (Henkensiefken, Bentz, Nantung, and Weiss, 2009). For these mortars, cracking was adequately wiped out for replacement levels more noteworthy than or equivalent to the 23.7 % of LWA by volume figured utilizing equation (3).

20
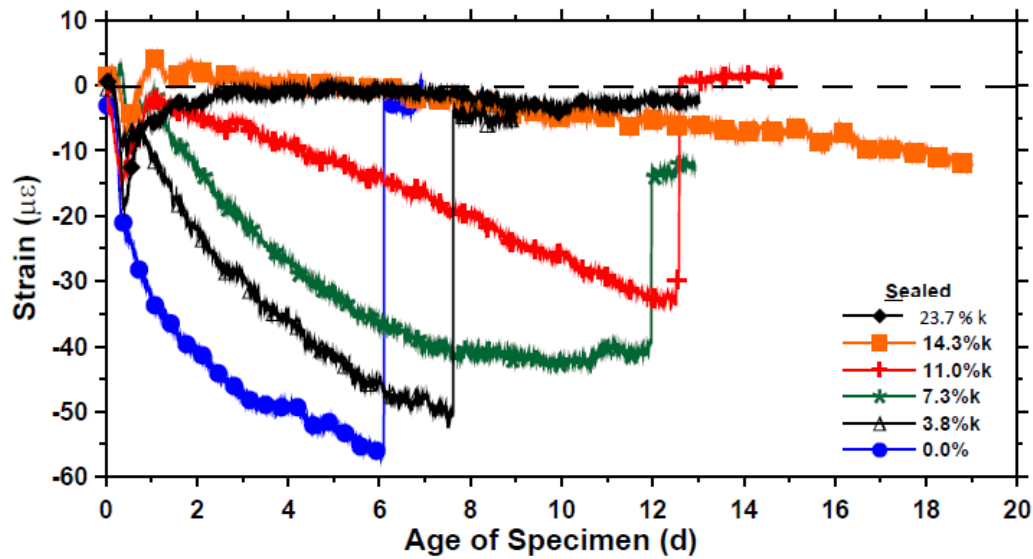
Figure 2-4: Reduced cracking with increased LWA replacements (Henkensiefken, Bentz, Nantung, & Weiss, 2009).

2.5.3 STRENGTH & ELASTIC MODULUS

The impacts of internal curing on compressive strength and elasticity rely on the mix design, curing conditions, and testing age. While mixtures with internal curing could enhance strengths and moduli because of enhanced level of hydration of the cementitious binder, on the other hand, a reduction in strength could be seen as the internal curing agents are mechanically weaker than the Normal Weight aggregates that they are replacing (Weiss, 2011). In general, declines are seen at before testing ages (< 7 d) while increments are acquired at later testing ages (Bentz and Weiss, 2011)

To better grasp the impact of curing conditions on compressive strength, Golias analyzed four mortar mixtures with w/c of 0.3 or 0.5 (Golias, 2010). For every w/c, one mixture had internal curing while the other did not. In the water-cured specimens, little contrast exists between the internally cured mortar and the plain mortar without internal

curing. This is normal since both mortars were given adequate outside water to help in hydration. In spite of the fact that the execution of the fixed examples was like that of the wet cured ones at early ages, the impact of extra curing water gets to be clear at the latest age (e.g., 91 d).

The impact of internal curing on modulus of elasticity is appeared can be concluded in figure 2-5. The modulus is lower for both frameworks containing LWA. A lessened elastic modulus can likewise be identified with the decrease in cracking potential (Weiss, Yang, and Shah, 1999) (Shah and Weiss, 2000) (Shin, Bucher, and Weiss, 2011) (Raoufi, Schlitter, Bentz, and Weiss, 2012).
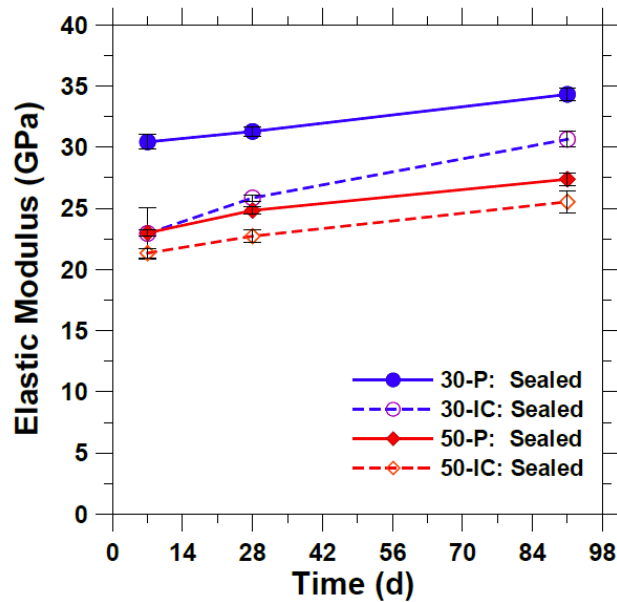
Figure 2-5: Influence of internal curing on elastic modulus of specimens (Golias, 2010).

Reducing the elastic modulus impacts lessening the residual stress because of restraint as a function of time. Raoufi et al. led a progression of reproductions to better comprehend the impact of lessened stiffness on early age cracking potential (Raoufi,

Schlitter, Bentz, and Weiss, 2012). Results from that study conclude that stresses are diminished by roughly 10 % to 20 %, because of the lessening in elastic modulus brought on by the LWA. The noteworthy impact of the water being discharged from the LWA to diminish shrinkage, and along these lines residual stress improvement, is likewise appeared in Figure 2-6.
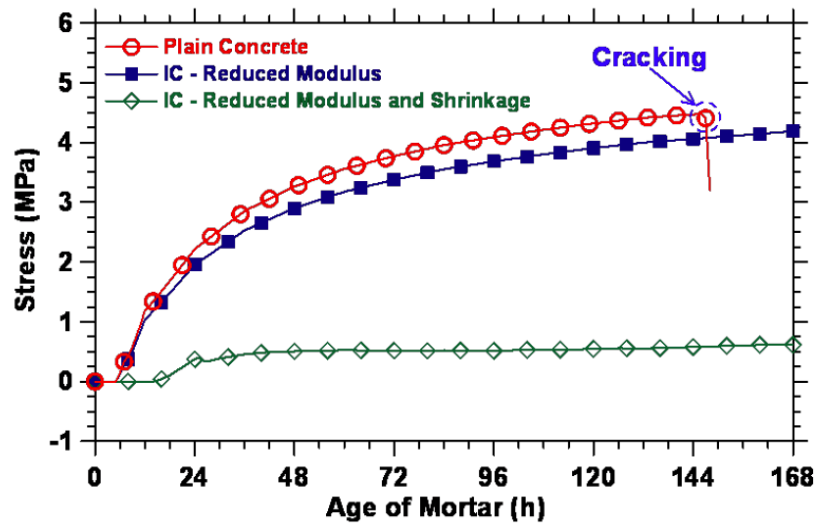
Figure 2-6: Influence of reduced elastic modulus on residual stress development (Raoufi, Schlitter, Bentz, & Weiss, 2012).

2.5.4 CREEP

Few studies concerning creep of frameworks with internal curing have been directed. Lopez et al. have analyzed the creep conduct of w/cm=0.23 high performance concretes with and without internal curing (Lopez, Kahn, and Kurtis, 2008). After wet curing, the typical weight high performance concrete showed generously higher compressive strengths than the concretes with internal curing at ages less than one year, and accomplished strengths in abundance of 100 MPa at 28 d. For this situation, supplanting the high quality rock utilized as a part of the control mixture with LWA in

23

the mixtures with internal curing delivered a sufficiently vast decrease in compressive strength that it couldn't be balance by upgraded hydration. The mixture with pre-wetted LWA displayed less creep (around 10 %) than the control mixture, while the mixture with dry LWA showed the best creep. On the other hand, Cusson and Hoogeveen measured a moderate increment in the tensile creep coefficient of w/c=0.34 concrete mixtures with internal curing measured at 7 d versus a control mixture (Cusson and Hoogeveen, 2008).

2.5.5 CURLING AND WARPING

By keeping up a higher and more uniform RH through the thickness of a concrete part, internal curing may give the extra advantage of lowering curling/warping. Wei and Hansen have watched that during a drying time of 16 d, warping was diminished by 70 % by mixing internal curing into a w/c=0.45 concrete (Wei and Hansen, 2008). This change in performance was expected both to the presence of water from the LWA throughout drying and the improved hydration delivering a denser layer of concrete at the top surface, along these lines diminishing the dissipation. Such results should be stretched out to longer drying periods to confirm the adequacy of internal curing for lessening warping in the more drawn out term.

2.5.6 TRANSPORT COEFFICIENTS AND SERVICE LIFE

Internal curing positively affects the transport coefficients and service life of cement-based materials. Improved hydration densifies the pore structure of the material, bringing about lessened transport. Regularly, the districts encompassing NWAs are a larger number of porous than the bulk hydrated cement paste and can give particular pathways to the ingress of harmful elements (Halamickova, Detwiler, Bentz, and

Garboczi, 1995). The replacement of a part of the NWAs by LWA could altogether decrease the availability of the districts encompassing the NWAs, and additionally lessen the volume division of this more porous paste (Bentz, 2009).

These positive characteristics of the LWA must be adjusted against the way that the LWA itself is a porous element that can contribute its own transport pathways. In light of this, the net impact of internal curing on transport will probably rely on upon the way of the cementitious framework. On the off chance that a high w/cm (> 0.45) is utilized, the narrow porosity may remain permeated and its permeated pathways can without much of a stretch connection up with those in the LWA to give expanded transport. Notwithstanding, in a lower w/cm grid, the narrow porosity will depercolate (Powers, Copeland, and Mann, 1959) and the porous LWA particles will soon be encompassed by a thick layer of hydration items. For sure, Zhang and Gjorv have watched that the penetrability of high-strength lightweight concrete is more reliant on the properties of the cement paste than the porosity of the LWA (Zhang and Gjorv, 1991). Moreover, Pyc et al. what's more, Castro et al. have as of late performed mass estimations that propose that once the pores in LWA void while supplying water to the hydrating cement paste amid internal curing, they are not accordingly resaturated, even upon complete inundation of the example (Pyc, Caldarone, Broton, and Reeves, 2008) (Castro, Keiser, Golias, and Weiss, 2011).

A few late studies have specifically inspected the impact of internal curing on chloride dissemination coefficients of mortars. Figure 2-7 demonstrates the assessed dispersion coefficients for w/c=0.4 mortars with and without internal curing (Bentz, Snyder, and Peltz, 2010). Huge diminishments in dissemination coefficients for high-

performance lightweight total concretes in respect to their typical weight partners have likewise been acquired by (Thomas, 2003). In that study, while transient dispersion coefficients were just diminished by 15 % to 25 % because of the consolidation of LWA, long haul (3 years) qualities were diminished by as much as 70 %.
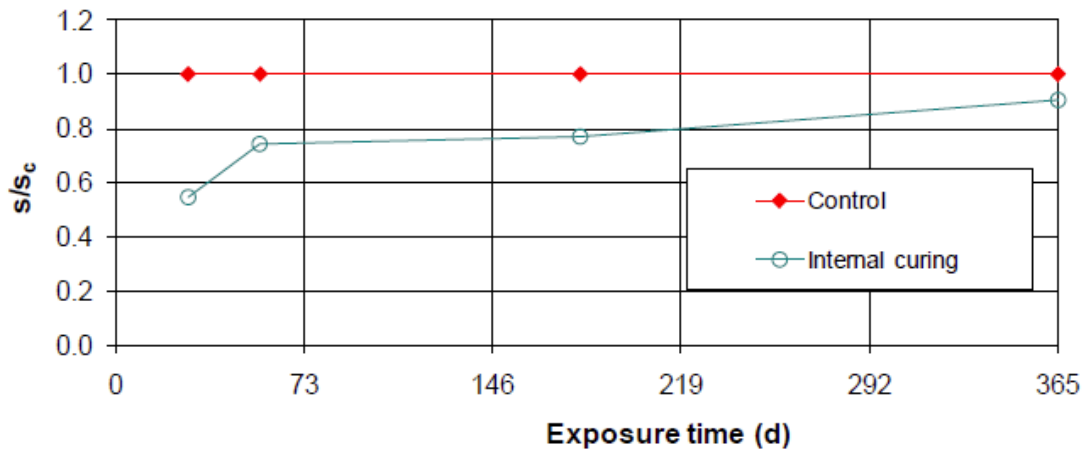
Figure 2-7: The diffusivity ratio S/Sc (proportional to the diffusion coefficient) for

w/c=0.4 mortars with and without internal curing (Bentz, Snyder, & Peltz, 2010).

As of late, Cusson et al. looked at the service lives of high-performance concrete bridge decks with and without internal curing (Cusson, Lounis, and Daigle, 2010). They contrasted a conventional concrete bridge deck with two high-performance decks, to be specific with and without internal curing. The high-performance concrete deck without internal curing gave a lessening in the normal dispersion coefficient for chloride assaulting the steel reinforcement, additionally showed introductory cracking because of intemperate early-age autogenous and warm stresses. The high-performance concrete with internal curing did not display any early-age cracking and gave a further 25 % decrease in the normal dissemination coefficient. The service life of a concrete highway bridge deck is generally defined as the time to reach critical damage levels, in terms of

delamination or spalling (Falling of concrete cover). In light of these and different suspicions exhibited in the study (Cusson, Lounis, and Daigle, 2010), the accompanying service life evaluations were acquired for the bridge decks: conventional concrete – 22 years, high-performance concrete without internal curing – 40 years, and high-performance concrete with internal curing – 63 years. For this situation, internal curing ought to create a bridge deck with an expanded service life and a fundamentally lessened life cycle cost
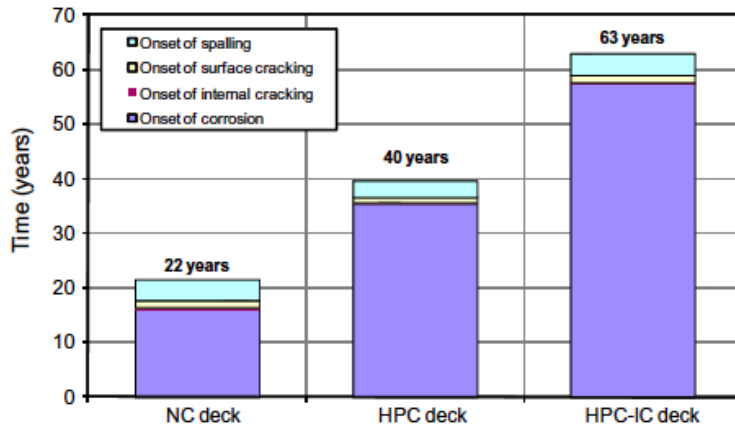
Figure 2-8: Service life predictions from deterministic service life models (Cusson, Lounis, and Daigle, 2010)

2.6 FIELD EXPERIENCES

As of the end of 2010, internal curing has been utilized in an assortment of concrete mixtures for differing applications including bridge decks, pavements, travel yards, and water tanks.

One of the initially recorded field investigations of concrete with internal curing was a vast railway travel yard in Texas requiring 190,000 m^3 of concrete, developed in 2005

(Villarreal and Crocker, 2007). In this application, a halfway measured LWA (178 kg/m^3 concrete) was mixed with NWAs to fill in a hole in the general total degree. The internal curing gave by the pre-wetted middle LWA brought about an observable (> 15 %) expansion in 28 day strength, disposal of plastic and drying shrinkage cracking, and a decrease in concrete unit weight that may interpret into diminishments in fuel prerequisites and gear wear (Villarreal and Crocker, 2007). Since 2007, a few informal break reviews have been directed at the railway travel yard, with just a few splits discovered (one of these being the place a development joint was coincidentally excluded). This concrete blend outline has relentlessly expanded in prevalence in the north Texas district (Villareal, 2008), with more than 2,000,000 m^3 of internally-cured concrete now set up.

In 2006, internal curing was utilized for persistently strengthened concrete asphalt set utilizing a slip-form clearing machine (Friggle and Reeves, 2008). The concrete mixture with internal curing was formulated to meet the Texas Department of Transportation (TxDOT) necessities of a base flexural strength of 3.93 MPa and a base compressive strength of 24.1 MPa, both at 7 days. Ten months after the effective placement of the asphalt, a break overview designated "a mind-boggling decrease in the quantity of splits (21 versus 52 in a similar segment of typical concrete) and a huge lessening in the deliberate width of the breaks" for the test area set utilizing the blend with internal curing in respect to a control segment put with the TxDOT standard blend (Friggle and Reeves, 2008).

Villarreal (2008) surveys past work by Villarreal and Crocker (2007) and talks about real usage and difficulties of utilizing lightweight aggregates in field. The most basic

challenge for utilizing lightweight aggregates as a part of the field for the reasons of internal curing is to accurately decide the moisture content of the aggregate. The aggregates must be soaked uniformly so that pumping of concrete with lightweight total is not influenced

Figure 2-9: Left - Internally cured concrete being cast at Bartell Road in New York (Wolfe, 2010), and Right - Internally cured concrete bridge deck being cast near Bloomington, IN (Di Bella, Schlitter, & Weiss, 2010).

2.7 POTENTIAL OF INTERNAL CURING

As internal curing keeps on progressing, examination on this point keeps on finding new roads for investigation. A standout amongst the most critical of these is the usage of crushed returned concrete aggregates as internal curing reservoirs. A late study has considered the mixing of crushed returned concrete aggregates (CCA) as a supportable way to deal with produce mortars with decreased autogenous deformation, yet comparable strength in respect to a control mortar arranged without internal curing (Kim and Bentz, 2008). While some decrease in measured autogenous deformation was delivered with the CCA alone as a replacement material, generously lower mortar shape

compressive strengths were likewise measured. Conversely, mixtures with a pre-wetted LWA as the replacement material showed a significant diminishment in autogenous shrinkage and a 10 % to 20 % strength increment at ages of 28 d and 56 d.

Using recycled aggregates as replacement to the coarse aggregates proved its soundness in previous research. Not only that, CCA proved to have high economic feasibility as well as major contribution to the environment (Abou-Zeid et al., 1998). Recycled aggregates have shown some potentiality to serve as internal curing agents. However, this opportunity was not given much attention in research, lab or field experiments.

2.8 SUPPOSITIONS

The literature review conducted reveals several primary lessons for efficient use of lightweight aggregates to provide internal curing:

- There is an optimal amount of aggregate replacement that will ensure that internal curing can occur. Increasing the aggregate replacement beyond this value has only a small effect on improving shrinkage properties and may have a detrimental effect on other important concrete properties (such as strength and abrasion resistance) (Ye et al., 2006).
- Lightweight aggregate replacement beyond 20% by volume of the total aggregate may significantly reduce strength (Ye et al., 2006).
- The effectiveness of the total is needy upon the total pore structure. By and large, bigger aggregates have a bigger pore structure, which brings about more productive internal curing (Hammer et al., 2004).

- Like the thought that adequately scattered air bubbles enhances durability, appropriately scattered lightweight aggregates enhances internal curing. Smaller total sizes are better scattered over bigger aggregates (Bentz, Snyder, and Peltz, 2010).

- Proper handling in the field is a critical thought that impacts the estimation of the LWA moisture content, even immersion of the LWA, and contamination of the aggregate. Consideration regarding appropriate handling strategies must be furnished to evade issues with yield, slump loss, pumping, and finishing (Villareal , 2008).

- There are few unexplored materials that have potential in internal curing that have not been yet examined or given enough attention. Using Recycled concrete aggregates for internal curing purposes shall be given more consideration

- It appears that internal curing has the potential to make a substantial impact on the durability and life-cycle costs of concrete structures. the reduced risk of cracking and the reduced chloride ingress should contribute to a more durable structure that has a longer life and lower life-cycle costs (Bentz and Weiss, 2011)

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The mechanical properties of concrete can play an important role in early age durability performance. Since concrete is a heterogeneous material, mechanical properties are affected by the independent properties of the concrete paste and aggregate. Therefore, substituting lightweight aggregate that is weaker and softer for normal weight aggregate may affect the overall mechanical properties of concrete. This chapter describes the procedures used in the laboratory, the materials, and equipment used to perform the evaluation of the mix designs as well as the test programs.

The experimental work herein includes fourteen core concrete mixtures prepared with four types of aggregates. The first is conventional dolomite aggregates. The second is recycled concrete aggregates. The third is perlite lightweight aggregate. The fourth and last is pumice lightweight aggregate. Water-cement ratio used was 0.35 to simulate the commonly used range in infrastructure concrete mixtures in Egypt.

3.2 MATERIALS AND PROPORTIONING

All the materials used in the experimental work were obtained from local Egyptian sources, with the exception of pumice lightweight aggregate that was imported from Greece. Their types and brands were selected from commonly used constituents of concrete mixtures in the Egyptian construction market. Each time a new aggregate sample was obtained, a new sieve analysis and specific gravity test were performed. The following sections describe the materials used in the study.

3.2.1 PORTLAND CEMENT

Ordinary Portland cement (ASTM C 150 Type I) was used. The cement was produced by Lafarge cement Egypt in Ain Sokhna plant. The cement had a specific gravity of 3.15 and a Blaine fineness of 313 m^2/kg. The Bogue compounds of the cement were as follows: C_3S = 61.07%, C_2S = 14.99%, C_3A = 2.06% and C_4AF = 15.03%. Chemical composition of cement used is shown in table 3-1 below

Table 3-1: Type I Portland cement characteristics

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl
Weight %	21.29%	3.93%	4.94%	64.37%	1.80%	1.99%	0.32%	0.35%	0.30%

Table 3-2: Typical results of standard testing of the cement used

Test	Standard(s)	Property	Results
Fineness of Portland Cement	ASTM C204	Fineness	313 m^2/kg
Density of Portland Cement	ASTM C188	Density	3.15
Setting Time of Portland Cement	ASTM C191	Initial setting	145 minutes
		Final setting	235 minutes
Compressive Strength of Cement Mortar	ASTM C109	3-day Comp. Strength	17.9 MPa
		28-day Comp. Strength	47.3 MPa

3.2.2 FINE AGGREGATES

Siliceous sand was used in all concrete mixtures. Fine aggregates were obtained from natural Wadi Sand, Bani Youssef. The sand had a fineness modulus of 2.547, a

saturated surface dry specific gravity of 2.64 and a percent absorption of 0.52%. Typical sieve analysis results of the sand are presented in Table 3-3 (along with the ASTM C33 limits for fine aggregate grading). Sieve analysis test was conducted according to ASTM C136. Several other tests were also conducted on the sand in order to determine its properties and the results were recorded as shown in table 3-4 below

Table 3-3: Fine aggregates Sieve analysis, % passing

Sieve Size (mm)	% Passing	ASTM C33 Limits
10.0	100.0	100
5.00	100.0	95-100
2.36	95.0	80-100
1.18	84.0	50-85
0.60	49.0	25-60
0.30	14.2	10-30
0.15	3.1	2-10
0.0075	0.6	0-2

Table 3-4: Typical results of standard testing of the fine aggregates used

Test	Standard(s)	Property	Results
Materials Finer Than 75μm (No. 200)	ASTM C117	Percent of Materials Finer Than 75μm (No. 200)	0.60 %
Chemical Analysis	BS 812 – Part 117/118	Chloride (CL)	0.0453%
		Sulphate (SO3)	0.40%
Clay Lumps & Friable Materials	ASTM C - 142	Percent of Clay Lumps & Friable Materials	0.65%
Specific Gravity & Absorption	ASTM C128	Bulk S.G (SSD)	2.638
		% Absorption	0.52 %

3.2.3   COARSE AGGREGATES

The conventional coarse aggregates used were crushed dolomite aggregate. Coarse aggregates were obtained from OCI Crusher, Attakah. The dolomite had a maximum nominal size of 20 mm, a saturated surface dry specific gravity of 2.57 and a percent absorption of 1.98%. Typical sieve analysis results of the dolomite are presented in Table 3-4 (along with the ASTM C33 limits for coarse aggregate grading). Sieve analysis test was conducted according to ASTM C136. Several other tests were also conducted on the dolomite in order to assess the properties and the results were recorded in table 3-6 shown below

Table 3-5: Coarse aggregates sieve analysis, % passing

Sieve Size (mm)	% Passing		ASTM C33 limits
	Dolomite Size 1	Dolomite Size 2	
37.50	100.0	100.0	
20.00	100.0	80.6	90-100
14.00	97.0	27.8	-
10.00	57.3	12.7	30-60
5.00	6.1	3.6	0-10
2.36	2.8	1.8	-
0.075	0.7	0.7	0-1

Table 3-6: Typical results of standard testing of the coarse aggregates used

Test	Standards	Property	Dolomite Size 1	Dolomite Size 2
Materials Finer Than 75μm (Sieve No. 200)	ASTM C117	% of Materials Finer Than 75μm	0.7 %	0.7%
Specific Gravity and Absorption of Coarse Aggregate	ASTM C127	Bulk S.G	2.570	2.572
		Absorption	1.98%	1.88%
Clay lumps & Friable Materials	ASTM C - 142	Clay Lumps & Friable Materials	0.07%	0.05%
Chemical Analysis	BS 812 – Part 117/118	Chlorides (CL)	0.021%	0.020%
		Sulphates (SO3)	0.28%	0.25%
Resistance to Abrasion (LAA)	ASTM C131	Percent loss	19.5%	19.5%

3.2.4   RECYCLED AGGREGATES

Concrete chunks resulting from the demolition of concrete which had an original strength 25-30 MPa was used. Recycled concrete aggregates were obtained from crushed concrete from demolishing works of science building in AUC's old campus, Tahrir square. The crushed material had a maximum size of 38 mm, a saturated surface dry specific gravity of 2.36 and absorption of 5.3%.

Figure 3-1: Demolishing of Science building of the American University in Cairo Tahrir Campus, October 2015, and crushing the concrete to the desired size.

3.2.5   LIGHTWEIGHT AGGREGATES

Two types of lightweight aggregates were used in different dosages. This was done to compare the effect of different lightweight aggregates in internal curing process. The two types were as follows:

3.2.5.1 STRUCTURAL PERLITE

Perlite was obtained from The Egyptian Company for Manufacturing Perlite plant, located in industrial district of Burj Al Arab city, Alexandria. Perlite had a specific gravity of only 0.32, and absorption of 32%. Perlite was supplied in 100 Litters plastic bags which weight almost only 9kg.

Figure 3-2: Structural Perlite bag and its grain size compared to crushed sand

3.2.5.2 PUMICE

Pumice was obtained from Laval mining and quarrying company, Greece. Its pumice quarry is located in Yali, Nissiros, a natural pumice deposit located in northern Greece. Pumice had a specific gravity of 1.1, and absorption of 18%

Figure 3-3: Pumice lightweight aggregates used

3.2.6   ADMIXTURES

The admixture used was a common ASTM C494 Type G; its commercial name is BASF MasterRheobuild-2270. The product is a modified lignosulfonate based with an approximate solid content of 39% and a specific gravity of 1.21

3.2.7   MIXING AND CURING WATER

Municipal water was used for washing aggregates as well as for mixing and curing concrete. The water used is drinkable water that is free from excessive amounts of acids, salts, alkalis and other materials that are harmful to concrete.

3.2.8   CURING COMPOUND

Curing compound used was BASF MasterKure 181, with specific gravity of 0.82. Curing compound assists in the retention of water during hydration. The resultant film retains sufficient moisture in the concrete to ensure full hydration of the cement; essential for optimum strength development.

Figure 3-4: BASF MasterCure 181 was used as a curing compound. It was added to a sprayer to be sprayed over the finished surface of concrete

3.2.9 MIXTURE PROPORTIONING

The 14 concrete mixtures had w/c of 0.35, Type "G" admixture, and cement content of 450 kg/m^3. It is very important to highlight that aggregates replacements were done on volume basis and not weight. Figure 3-2 illustrates the Mixutres used.
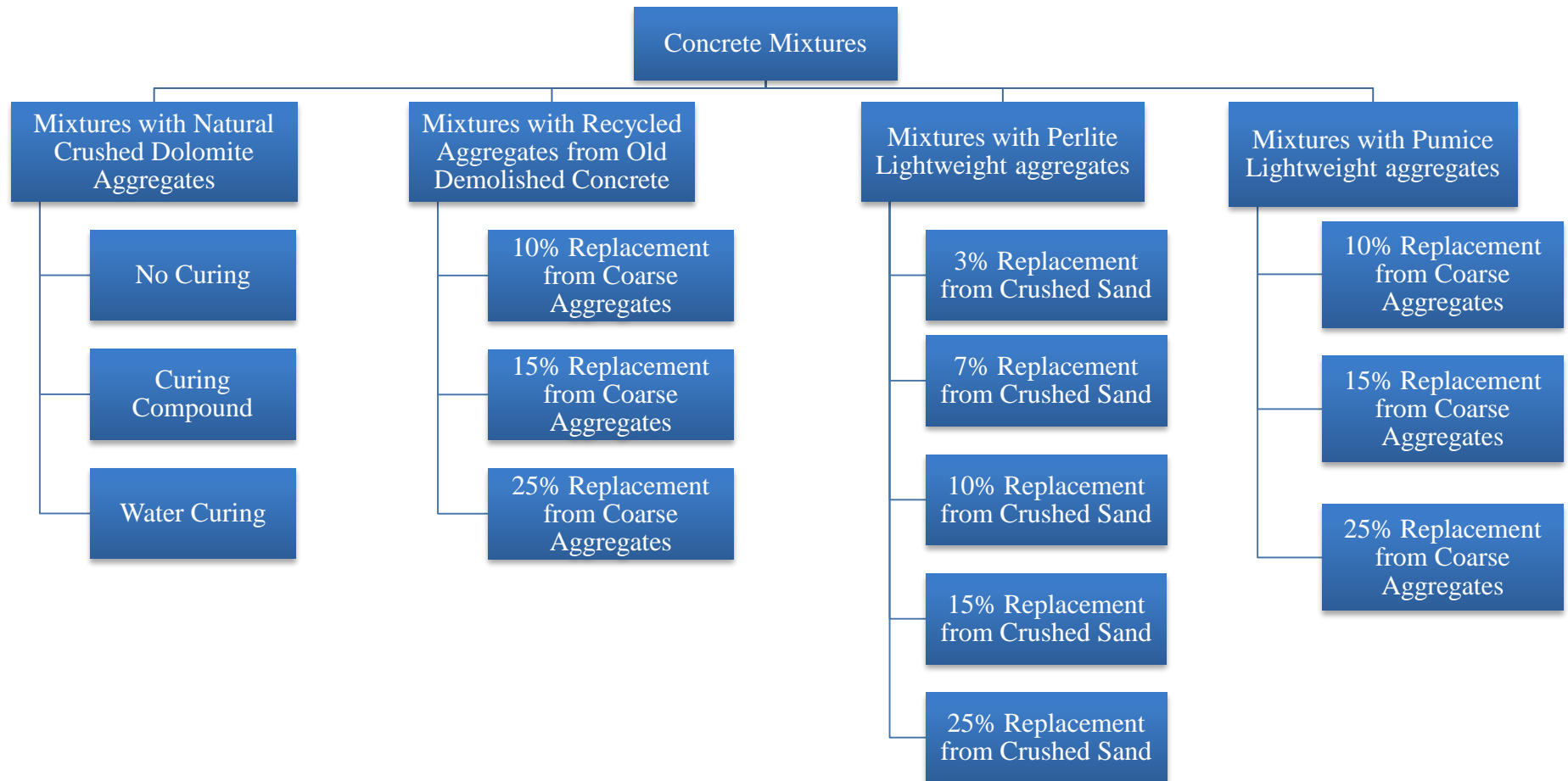
Figure 3-5: Diagram Illustrating all mixtures used in this study

First set is conventional concrete mixtures; which was cured in three different ways: Full curing by submerging specimens in curing tanks, the use of a curing compound and with no curing.

Table 3-7: Conventional Concrete mixture

Material (kg/m³)	C-50 Conventional Concrete
Cement	450
Aggregate Size 1	525
Aggregate Size 2	525
Fine Aggregates	662
Free Water	147
Absorption Water	23
Crushed Sand	112
Admixture – RH 2270	7.5

Second set constitutes 3 mixtures of prewetted recycled concrete aggregates with dosages of 10%, 15% and 25%. Recycled aggregates replaced size 1 and size 2 aggregates because of similar size to obtain similar gradation.

Table 3-8: Mixtures with replacements of Recycled Concrete Aggregates

Material (kg/m³)	10% Recycled	15% Recycled	25% Recycled
Cement	450	450	450
Aggregate Size 1	472.5	446.25	393.75
Aggregate Size 2	472.5	446.25	393.75
Fine Aggregates	662	662	662
Free Water	147	147	147
Absorption Water	20.7	19.6	17.25

Crushed Sand	112	112	112
Admixture – RH	7.5	7.5	7.5
Recycled Aggregates	105	157.5	262.5

Perlite specimens come with 5 different dosages of prewetted pelite aggregates, 3%,7%,10%,15% and 25%. Perlite aggregates replaced crushed sand because of similar size to obtain similar gradation

Table 3-9: Mixtures with replacements of Perlite lightweight aggregates

Material (kg/m^3)	3% Perlite	7% Perlite	10% Perlite	15% Perlite	25% Perlite
Cement	450	450	450	450	450
Aggregate Size 1	525	525	525	525	525
Aggregate Size 2	525	525	525	525	525
Fine Aggregates	642	615	596	562	496
Free Water	147	147	147	147	147
Absorption Water	23	23	23	23	23
Crushed Sand	110	108	106	103	98
Admixture – RH	7.5	7.5	7.5	7.5	7.5
Perlite	2.6	6	8.7	13	21.7

The remaining 3 mixtures contain prewetted pumice aggregates with concentrations of 10%, 15% and 25%. Pumice lightweight aggregates replaced size 1 and size 2 aggregates because of similar size to obtain similar gradation.

Table 3-10: Mixtures with replacements of Pumice lightweight aggregates

Material (kg/m^3)	10% Pumice	15% Pumice	25% Pumice
Cement	450	450	450
Aggregate Size 1	472.5	446.25	393.75
Aggregate Size 2	472.5	446.25	393.75
Fine Aggregates	662	662	662
Free Water	147	147	147
Absorption Water	20.7	19.6	17.25
Crushed Sand	112	112	112
Admixture – RH	7.5	7.5	7.5
Pumice	49.5	74	123.7

3.3 EXPERIMENTAL WORK

This section describes the testing carried on constituent raw materials, and preparation, mixing, casting and curing of concrete specimens. This section also discusses fresh and hardened testing of concrete as well as the durability testing.

3.3.1 AGGREGATES TESTING

The following tests were carried out in compliance with the following ASTM standard specifications:

- Sieve analysis of fine and coarse aggregates in accordance with ASTM C136.

- Materials finer than 75µm (No. 200) sieve in mineral aggregates by washing in accordance with ASTM C117.

- Specific gravity & absorption of fine aggregate in accordance with ASTM C128.

- Specific gravity & absorption of coarse aggregate in accordance with ASTM C127

- Resistance to abrasion of small size coarse aggregate by use of the Los Angeles machine in accordance with ASTM C131.

3.3.2 CEMENT TESTING

The following tests were carried out in compliance with the following ASTM standard specifications:

- Fineness of Portland cement by air permeability apparatus in accordance with ASTM C204.

- Density of hydraulic cement in accordance with ASTM C188.

- Time of setting of hydraulic cement by Vicat needle in accordance with ASTM C191.

- Compressive Strength of Hydraulic Cement Mortar in accordance with ASTM C109.

3.3.3 SPECIMEN PREPARATION

Concrete specimens for each one of the 14 mixtures. Each mixture had the following specimens:

- Standard cubes complying with BS 1881 (150 x 150 x 150 mm) for testing 7,28 and 56 days

- Standard ASTM C 78 flexural strength beams (150 x 150 x 75 mm) for testing 28 and 56 days.

- Standard ASTM C 39 for preparing concrete cylinders (150 x 300 mm), for Rapid Chloride Permeability Test (RCPT) in 28 and 56 days.

- Standard tile (200 x 200 x 25mm) for testing Abrasion resistance throughout age of specimen.

- Standard ASTM C157/C157M prism of 100-mm square cross-section and approximately 285 mm long for testing shrinkage.

3.3.4 MIXING

Mixing was performed in accordance with ASTM C192-07. The LWA was oven dried, air cooled, and then submerged in water for 24 h ± 1 h before mixing. All aggregates were mixed in SSD condition. All batches were mixed using a counter-current pan mixer. The batch size for all of the batches was 0.06 m^3. Mixing procedure went as follows: first, aggregate was loaded into the mixer. The mixer was started and 50% of the total water was added. The cement and remaining mixing water containing the admixture were then added. The mortar was mixed for 3 min, and then rested for 1 min while the sides of the mixer were scraped, then mixed for a final 2 min.

Figure 3-6: Mixing of concrete constituents using 0.06m^3 mixer

3.3.5 CASTING

Specimens were cast immediately following the testing of the concrete slump, air content and unit weight. After the molds were coated with a layer of oil (to help in the removal of the specimens), concrete was placed within the molds in three equal layers. After adding each layer of concrete, the concrete was consolidated using a tamping rod as per specification. Specimens were de-molded 24 hours after casting.

Figure 3-7: Placing and finishing of concrete specimens

3.3.6 CURING

Specimens were cured in 3 different modes. The first one was full curing, were the specimens were submerged in curing tank till testing day, this was once made for the conventional concrete mixture with full curing mode. The second one was curing using curing compound. After casting, curing compound (diluted with 1:6 water) was sprayed on the exposed surface of the specimen. This was done once for the conventional concrete mixture with curing compound mode. All the remaining mixtures were not cured, left in the open air to simulate reality. These mixtures were done to simulate no curing mode of the conventional concrete mixture and allow for simulation of internal curing of the 3 different aggregate types.

3.3.7 FRESH TESTING

- Slump of Portland Cement Concrete in accordance with ASTM C 143.

- Unit weight of Fresh Concrete in accordance with ASTM C 231

- Air Content of Freshly Mixed Concrete by the Pressure Method in accordance with ASTM C 231.

3.3.8 HARDENED CONCRETE TESTING

- Compressive Strength: Compressive strength of Concrete Cubes This test was carried out according to standard after 7, 28 and 56 days using an "ELE" brand machine of 2000 kN capacity.

- Flexural Strength: Flexural strength of Concrete Using Simple Beam with Third-Point Loading (ASTM C78). This test was carried out after 28 and 56 days using the same "ELE" brand machine used for the compressive strength test.

3.3.9 DURABILITY TESTING

- Rapid Chloride Permeability Test: The rapid chloride-ion penetration test was conducted through passing electric charges into concrete discs according to ASTM C 1202.

- Abrasion: Resistance to abrasion resistance was evaluated through applying rotary abrasion of gritty sand on 200x200x25 mm specimens. Assessment is carried out based on weight loss criteria.

- Shrinkage Assessment: Shrinkage was evaluated through dimension inspection of the 200x200x25mm specimen in 7, 28 and 56 days. This was used to assess the volumetric change in each mixture.

Figure 3-8: Prisms and apparatus used to perform shrinkage assessment test (Abou-Zeid, et al. 2015)
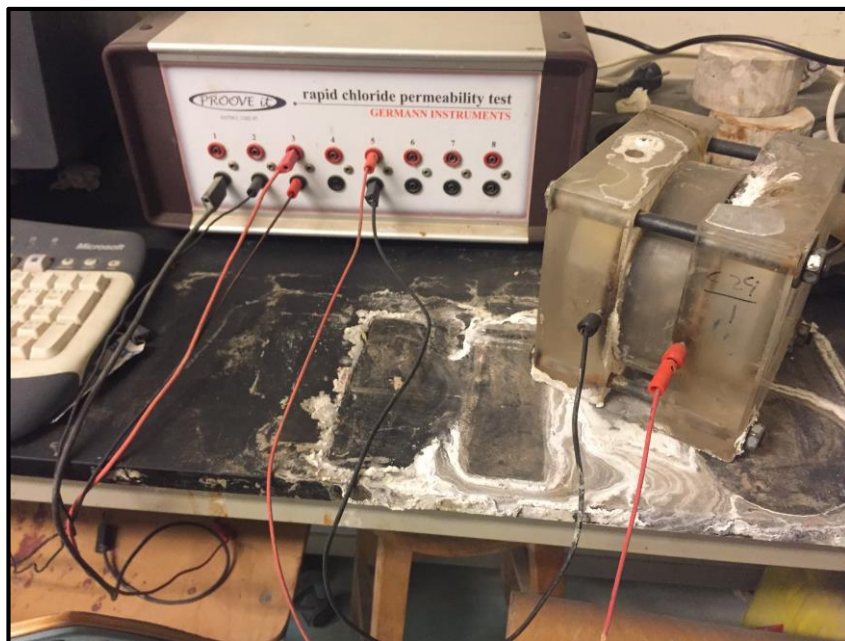
Figure 3-9: Setup of the Rapid Chloride Permeability Test

CHAPTER 4

RESULTS AND ANALYSIS

This section describes the properties and test results of fresh concrete, handed concrete and durability. Results are presented and analyzed to better understand the technology of internal curing using different replacements of different aggregate types. It is worth mentioning that workmanship does not often do good curing, so perfect curing is theoretical.

4.1 FRESH TESTING

The following are the results of the air content, unit weight, and slump of lightweight, recycled as well as conventional concrete specimens:

Table 4-1: Fresh Testing Results of all concrete mixtures

Mixture	Slump (mm)	Air Content (%)	Unit Weight (kg/m³)	Temperature (°C)
Conventional	130	2	2444	22
Recycled 10%	130	2.4	2401	24
Recycled 15%	140	2.6	2358	25
Recycled 25%	160	3.0	2339	24
Perlite 3%	140	2.0	2424	26
Perlite 7%	160	2.1	2407	25
Perlite 10%	190	2.2	2393	24
Perlite 15%	220	2.4	2336	24
Perlite 25%	250	2.7	2325	25
Pumice 10%	150	2.6	2384	23
Pumice 15%	180	3.0	2327	23
Pumice 25%	210	3.3	2248	23

4.1.1 SLUMP

The results of slump test are listed in table 4-1 and are illustrated in figure 4-1. As can be seen in figure 4-1, the slump ranges from 130 to 250 mm. The highest values were obtained from the samples with lightweight aggregates replacements, especially perlite. Slump values are highest for perlite mixtures, followed by pumice then recycled aggregates. The lowest slump values were those of the concrete made with conventional aggregates. Slump values increased with higher replacements of saturated aggregates. The higher slump values of the pre wetted aggregate mixtures can be attributed to the desorption property of those types of aggregates, or their ability to lose their internal water. This water was released from the aggregates during mixing causing an increase in the flow ability of the concrete mixture.
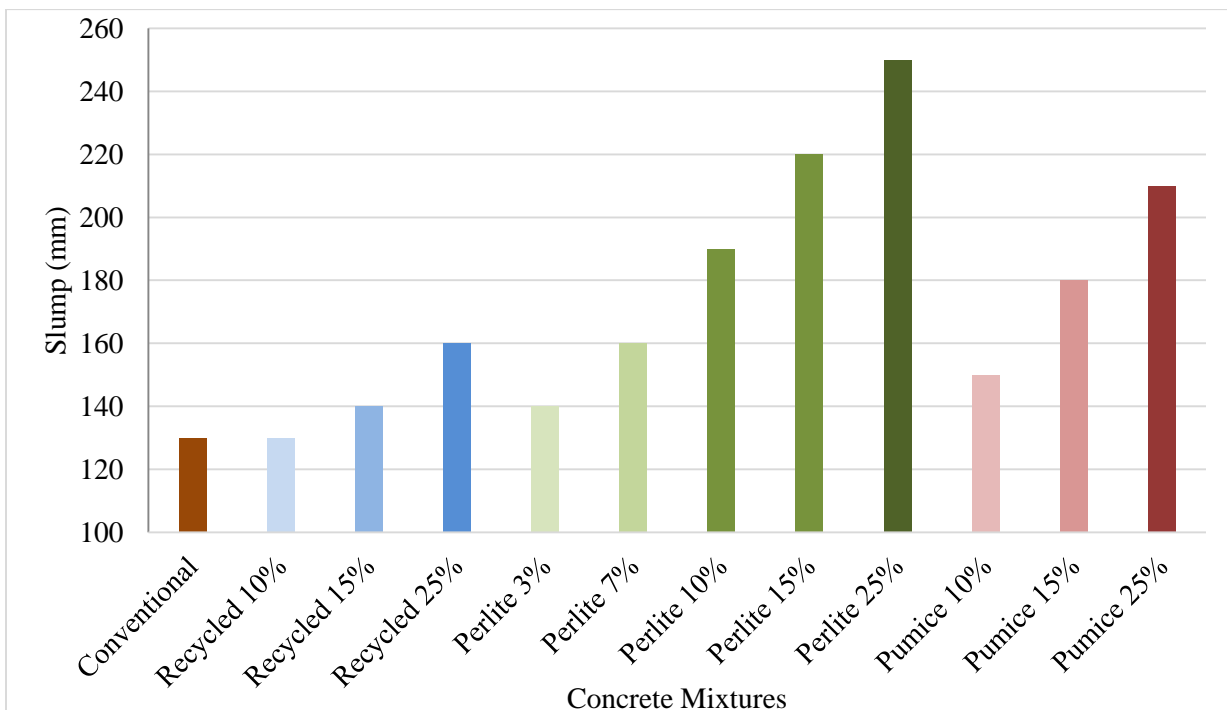
Figure 4-1: Slump test results for different concrete mixtures

Desorption shows to be lower for recycled aggregates and pumice compared to the perlite mixtures, thus yielding slightly lower slump values. Results also reveal that conventional concrete had the lowest slump of 130 mm. This is due to the absence of additional water in the aggregate, since the conventional aggregates were SSD state. Slump test results reveal an important advantage of using pre-wetted aggregates, which is enhanced workability that shall ease concrete handling and finishing.

Figure 4-2: Picture showing difference in slump between Conventional mixture (left) and Perlite mixture (right)

4.1.2 AIR CONTENT

Results of Air content test are listed in table 4-1 and are illustrated in figure 4-3. As can be seen in figure 4-3, the air content percentage ranges between 2 to 3.3%. The highest values were obtained for mixtures with pre-wetted lightweight and recycled aggregates, pumice, recycled and perlite mixtures, respectively. Generally, Air content increased with the elevated replacements. The lowest air content results were those of the conventional mixtures.

Figure 4-3: Air Content test readings for 2 different mixtures
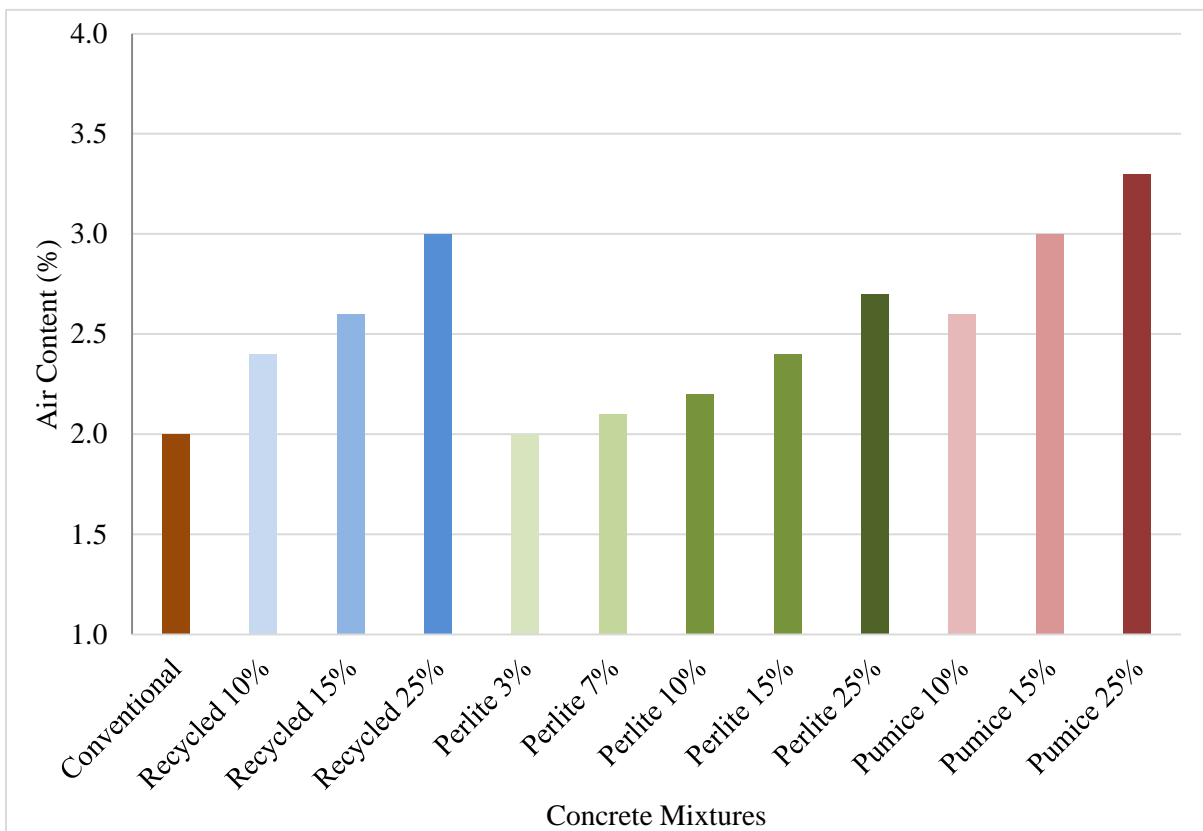
Figure 4-4: Air content results for different concrete mixtures

The increase in air content for mixtures with aggregates replacements can be attributed to the porosity of those types of aggregates. Lightweight and recycled aggregates are by nature mire porous than dolomite aggregates used in conventional

concrete mixtures. This increased the entrapped air in the concrete mixture. Among the saturated aggregates mixtures, perlite mixtures appeared to be the least. This can be explained mainly because perlite replaced crushed sand, which occupies the least volume compared to the coarse aggregates. Also, from visual inspection, Pumice appears to be the most porous, which is reflected on the results. Generally, Air content results reveal that mixtures with replacements of lightweight and recycled aggregates yield slightly higher air content.

4.1.3 UNIT WEIGHT

The results of unit weight test are listed in table 4-1 and are illustrated in figure 4-5. As can be seen in figure 4-5, unit weight results range from 2248 to 23444 kg/m3. The highest value was obtained for concrete mixtures made with conventional dolomite aggregates. Unit weight values were slightly decreased for mixtures with aggregate replacements of recycled, perlite, and pumice, respectively. Also, unit weight dropped with increased replacement percentage of pre wetted lightweight and recycled aggregates. This behavior can be attributed to the increased porosity and decreased unit weight of the replacement aggregates compared to the dolomite aggregates used in conventional mixtures. Within the replacement aggregates mixtures, unit weight decreased for aggregates with lower unit weight. However, it is worth noting that the decrease in unit weight for replacing aggregates mixtures was slight compared to conventional dolomite aggregate mixtures. This happened mainly because the replacing aggregates were saturated with water, which makes such aggregates closer in density to those conventional aggregates. Generally, replacing conventional aggregates with recycled or lightweight aggregates led to slight drop in unit weight in the concrete mixture.
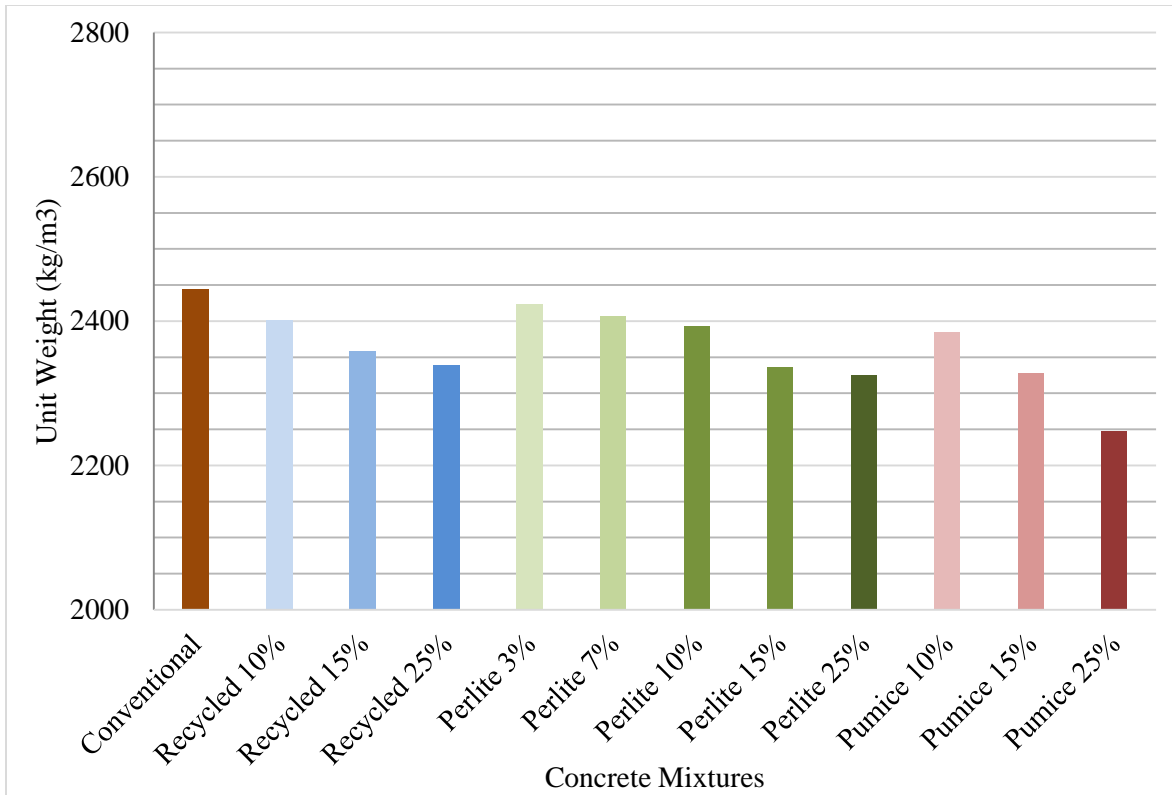
Figure 4-5: Unit weight results for different concrete mixtures

4.1.4 TEMPEREATURE

Results of temperature test are listed in table 4-1 and are illustrated in figure 4-6. As can be seen in figure 4-6, temperature results range from 22 to 25 degree Celsius. There was no clear correlation between temperature and the mixture, temperature was rather affected by both ambient temperature and temperature of the mixing water. Generally, replacing conventional aggregates with pre wetted lightweight or recycled aggregates have no effect on the temperature of the mixture.
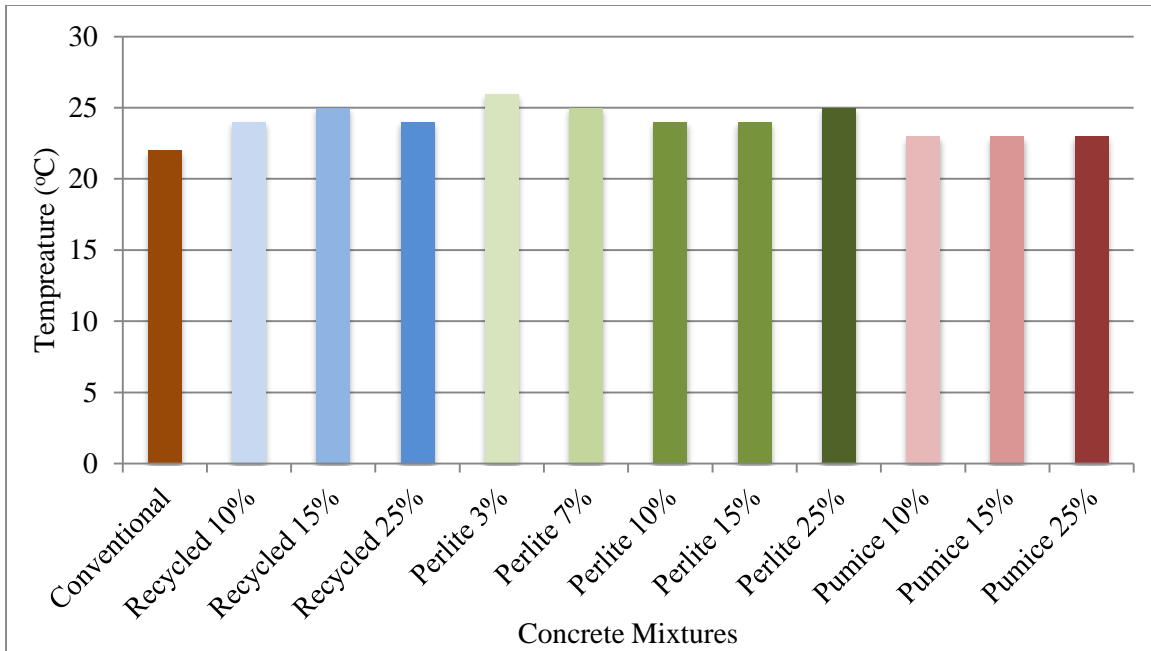
Figure 4-6: Results of fresh concrete temperature

Incorporating lightweight and recycled concrete aggregates affected the fresh properties of concrete. Mixtures with lightweight or recycled concrete aggregate replacements enjoyed better workability. As these aggregates were pre-wetted for 24 h ± 1 h, they may have lost some of this water to the surrounding paste, causing lower slumps and hence better workability. Aggregate replacement also affected the air content. As these aggregates are by generally more porous than the dolomite aggregates, they may experience higher voids. Air content was higher towards use of coarser replacing aggregates like recycled concrete and pumice aggregates, this may happened because of better interlocking of smaller sized aggregates like perlite. Unit weight was slightly affected. Mixtures with replacements of lightweight or recycled concrete aggregates showed lower unit weight. Unit weight decreased with the increased dosages of lightweight and recycled concrete aggregates. This happened because of porous

55

aggregates used. Temperature results showed no significant effect in cases of replacement, temperature was rather affected by ambient and mixing water temperatures. It can be concluded that mixtures with replacements of lightweight and recycled concrete aggregates have higher workability and air contents and lower unit weights.

4.2 HARDENED TESTING

The following are the results of the compressive strength, and flexural strength of lightweight, recycled as well as conventional concrete specimens:

Table 4-2: Hardened concrete test results for different mixtures

Mixture	Compressive Strength (MPa)			Flexural Strength (MPa)		Flexure to Compression Ratio
	7d	28d	56d	28d	56d	56d
No Curing	54.5	59.7	61.8	5.5	5.8	9%
Curing Compound	57.2	63.3	65.6	6.1	6.4	10%
Water Curing	54.1	63.4	66.5	6.3	6.6	10%
Recycled 10%	50.3	56.0	58.7	7.2	7.5	13%
Recycled 15%	49.5	52.3	54.9	7.7	8	14%
Recycled 25%	46.3	51.9	54.5	6.9	7.1	13%
Perlite 3%	53.1	57.4	60.6	5.7	5.9	10%
Perlite 7%	52.7	58.8	61.7	5.8	6.1	10%
Perlite 10%	52.3	59.7	62.7	6.1	6.4	10%
Perlite 15%	51.8	57.4	60.8	5.2	5.5	9%
Perlite 25%	48.3	55.3	57.9	4.4	4.6	8%
Pumice 10%	50.6	57.1	59.9	4.6	4.8	8%
Pumice 15%	47.8	51.1	53.8	4.7	4.9	9%
Pumice 25%	40.6	45.7	48.2	5.1	5.3	11%

4.2.1 COMPRESSIVE STRENGTH

Results of the compressive strength test are listed in table 4-2 and are illustrated in figure 4-7. As can be seen in figure 4-7, the 56-day compressive strength results range from 48.2 to 66.5 MPa. The highest value was obtained for the standard concrete mixture made with conventional dolomite aggregates namely full curing followed by curing compound and no curing modes. The high values of compressive strength can be attributed to the strength of the conventional dolomite aggregates compared to the replacement aggregates. Curing mode and its effect on the strength can be clearly outlined, a drop in strength is found between fully and non-cured samples. This can be explained through the incomplete hydration process in non-cured samples compared to curing compound or full curing samples.

As for the pre wetted lightweight and recycled aggregates results, as can be seen in figure 4-7, perlite showed the highest results followed by recycled then pumice aggregates mixtures. This is mainly due to the fact that both recycled and pumice replaces coarse aggregates size one and two contrasting to perlite, which replaces crushed sand. Coarse aggregates are the main load carrier and hence the replacement directly affected the strength. It is worth noting that 10% replacement with perlite aggregates surpassed the no curing sample of conventional concrete. This is primarily explained by the enhanced hydration process through the internal moisture supplied by water stored inside the perlite aggregates. Perlite is also considered to be better dispersed through the concrete section compared to the pumice and recycled aggregates due to its finer grain size. Generally, results show that compressive strength is mainly affected by the strength of the replacing aggregates and the replacing aggregate type (coarse or crushed sand).

Dispersion is also an important factor that affect internal curing performance of the aggregates, the finer the aggregate the better dispersion and scatter through the concrete section. The 10% aggregate replacement with perlite lightweight aggregate showed to be promising after surpassing the non-cured sample after 56 days.
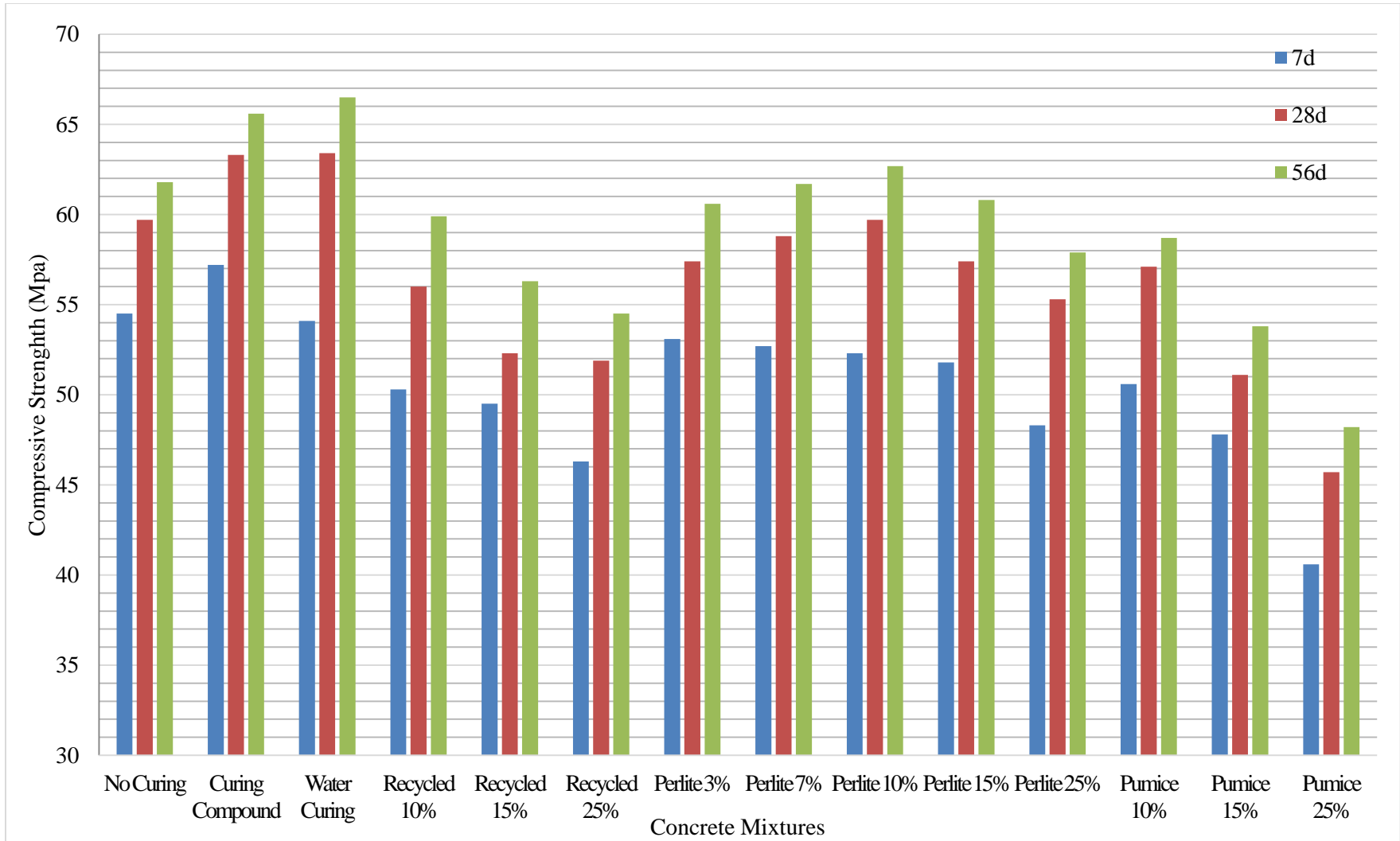
Figure 4-7: Compressive strength results for different concrete mixtures

It can be concluded that Compressive strength showed to be clearly affected by both aggregate type and curing mode. Within the same testing date, strength differed from one aggregate type to the other based also on replacement dosages. So, the weaker the aggregate used with higher dosages the more the strength in affected. Perlite is the weakest aggregate type followed by pumice, recycled concrete and conventional aggregates, respectively. Strength gaps appeared clearly in recycled aggregates and Pumice mixtures as they were used in high dosages, in contrast to perlite, which was used with lower dosages (by volume). Curing mode affected strength, as observed no curing mixture showed highest values at 7 days however was surpassed by curing compound and full curing later in 28 and 56 days. This can be explained because of the potential inside cracks (desiccation) caused by the incomplete hydration due to the lost water. Despite the fact the perlite is the weakest aggregate type, it yielded the most strength within the internally cured specimens, principally the 10% dosage. This can be explained due to the better dispersion of the aggregate throughout the concrete section, compared to the coarse aggregates. Also, perlite dosage replaced the crushed sand aggregates, which is not the primary load carrier in concrete. At 56 days, 10% perlite surpassed the standard no curing mixtures, asserting on the importance of curing and its role in strength development. Aggregate type, dosage and dispersion are the 3 principal factors that affect the strength of internally cured concrete.

4.2.2 FLEXURAL STRENGTH

The results of the flexural strength test are listed in table 4-2 and are illustrated in figure 4-8. As can be seen in figure 4-8, flexural strength results range from 4.6 to 8.0 MPa. The highest value was that of the 15% recycled aggregates. This can be attributed

to the Interfacial Transition Zone (ITZ) between aggregate surface and concrete paste. The ITZ has enhanced the properties internally, which means less tendency of aggregate pop out, thereby higher flexural strength. Also, Recycled aggregates have a angular texture, causing better interlocking of aggregates with the paste. It is worth noting that flexural strength dropped for the increased replacement percentage, mainly because of the excessive replacement of dolomite aggregate which has higher strength compared to other replacing aggregates.

These outcomes have fairly comparable patterns to the patterns of the compressive strength as in increasing the percentage of perlite or recycled aggregates leads to some decrease in flexural strength. Contrastingly, a large portion of the mixtures made with perlite or recycled aggregates recorded a flexural strength that is higher than the conventional concrete mixtures. This highlights the internal curing impact of the perlite and recycled aggregates in minimizing cracking.. With respect to conventional mixtures, the impact of curing was more proclaimed than the compressive strength mixtures. Generally, the consolidation of perlite prompted a reduction in flexural strength while the replacements of recycled aggregates prompted flexural strength that is comparative or surpassing ordinary mixtures. The outcomes in this propose the flexural strength test has a superiority to distinguish the impact of internal curing than compressive strength.
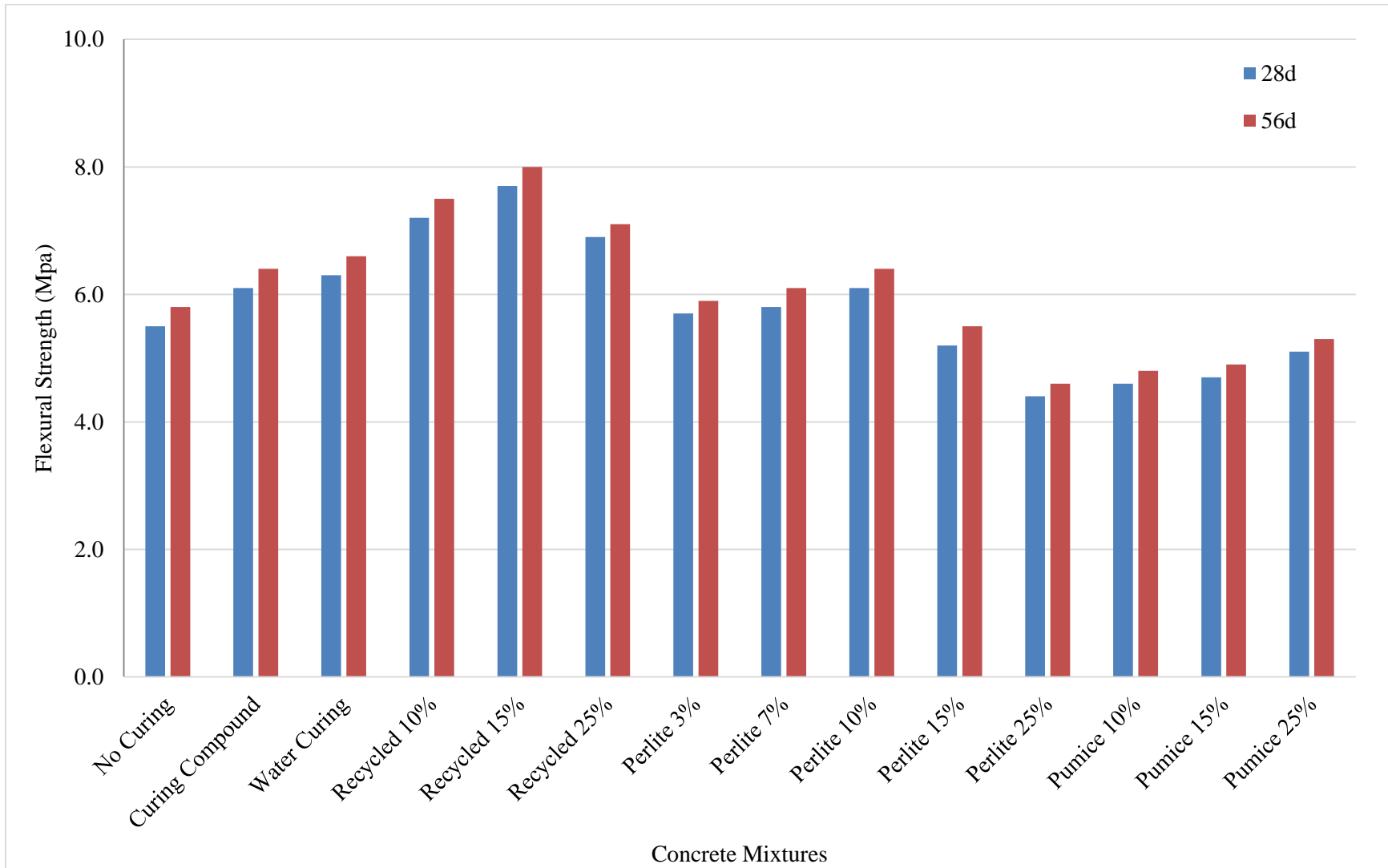
Figure 4-8: Flexural strength results for different concrete mixtures

4.2.3 FLEXURAL STRENGTH TO COMPRESSIVE STRENGTH RATIO

Results of the flexural/compressive ratio are listed in table 4-2 and are illustrated in figure 4-9. As can be seen in figure 4-9, the ratio of flexural/compressive values range from 8% to 14%. The highest value is that of the 15% recycled concrete mixture. This can be attributed to the high flexural strength results obtained for the same mixture. The high values of flexural strength was reached mainly due to the enhanced Interfacial Transition Zone that gave better bonding of recycled aggregates and the rest of the concrete mixture. The relatively high percentage of flexural to compressive strength gives indication of better resistance to tensile forces that eventually should lead to lowered cracking.
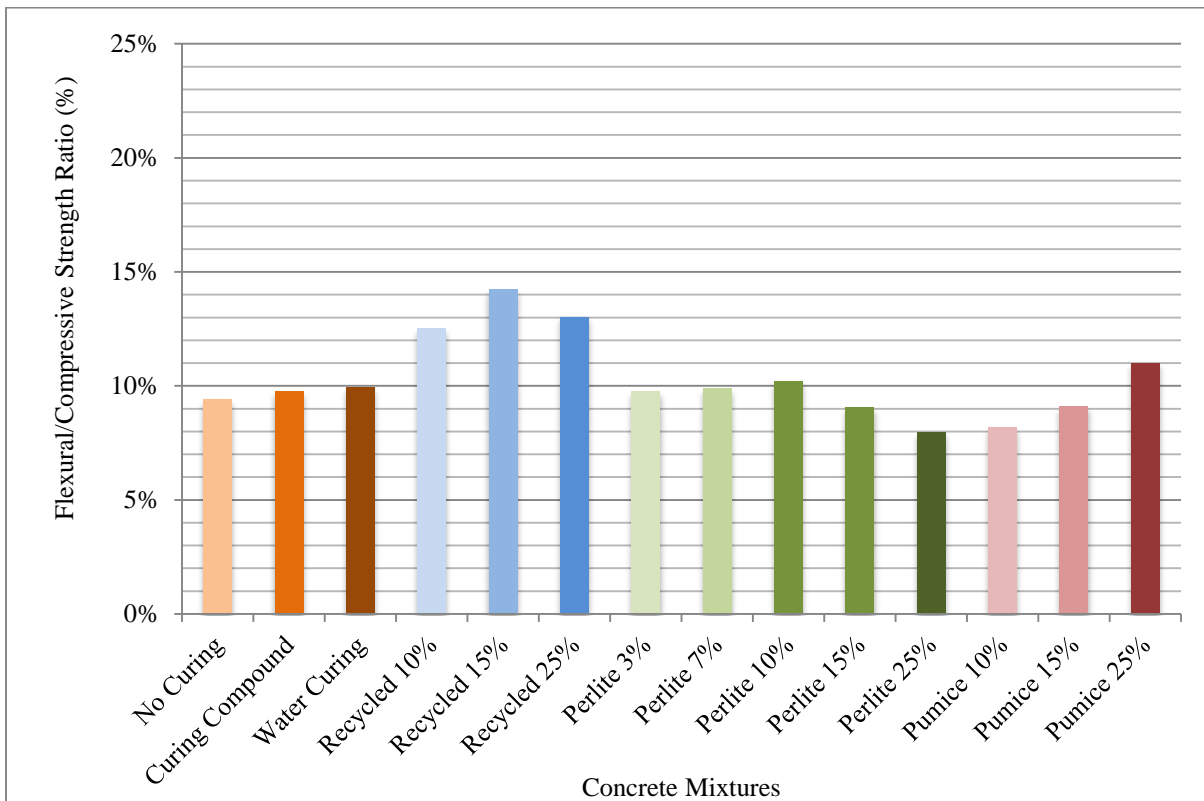
Figure 4-9: Flexural Strength to compressive strength ratio for different concrete mixtures

4.3 DURABILITY TESTING

The following are the results of the Shrinkage assessment, RCPT and abrasion resistance of lightweight, recycled as well as conventional concrete specimens:

Table 4-3: Durability testing results for different concrete mixtures

Mixture	Shrinkage (x0.01 mm)			RCPT (Coulombs)		Abrasion - Lost thickness (mm)
	7d	28d	56d	28d	56d	
Std. No Curing	2.22	3.12	3.69	1564	1588	1.9
Std. Curing Compound	2.13	2.82	3.34	1252	1224	1.6
Std. Full Curing	1.98	2.68	3.19	1232	1202	1.3
Recycled 10%	1.48	1.72	1.95	1984	1976	2.6
Recycled 15%	1.22	1.62	1.77	2030	2011	2.8
Recycled 25%	1.14	1.48	1.62	2168	2154	3.1
Perlite 3%	2.13	2.89	3.12	1412	1348	1.9
Perlite 7%	1.77	2.64	2.92	1422	1348	2.1
Perlite 10%	1.43	2.32	2.57	1437	1420	2.3
Perlite 15%	1.21	2.21	2.39	1582	1477	2.8
Perlite 25%	0.98	1.88	2.21	1642	1589	2.7
Pumice 10%	1.45	1.67	1.98	2320	2288	2.8
Pumice 15%	1.12	1.53	1.73	2210	2198	2.9
Pumice 25%	1.07	1.44	1.57	2651	2598	3.4

4.3.1 SHRINKAGE ASSESSMENT

The Results of shrinkage assessment test are listed in table 4-3 and are illustrated in Figure 4-10. As can be seen in figure 4-10, the shrinkage values range from 1.57 to 3.69 (x0.01) mm. The highest values were obtained for cases of conventional concrete,

particularly the non-cured specimens. This can be attributed to the poor hydration performance of the non-cured specimens. To the contrary, the internally cured mixtures showed decreased shrinkage; the mixtures with 25% recycled aggregates, with shrinkage of 0.0162 mm, had almost half of value of the conventional concrete shrinkage of 0.0369 mm. At the start, one can see that the vast majority of the shrinkage occurred until 28 days and less increment in shrinkage was seen in the interim somewhere around 28 and 56 days. All internal curing mixtures of perlite, pumice and the recycled aggregates had critical impact in decreasing shrinkage. Such reduction in shrinkage qualities was higher after increasing the perlite, pumice and reused aggregates dosages. The recycled aggregates and pumice, in any case, demonstrated the most reduced shrinkage of all mixtures notwithstanding when contrasted with perlite blend.

Shrinkage assessment test highlights the significance of internal curing. The internally cured concrete mixtures had the lowest shrinkage values and lowest shrinkage development through the 56 days. This is clearly due to the enhanced hydration process. The internal moist stored inside the concrete section helped in better commencement of strength and durability development of the mixture and lowered or eliminated self desiccation. Decreased shrinkage of internally cured concrete reveals the potential of this technology, especially in concretes with special functions that require minimizes shrinkage and accordingly, cracking.
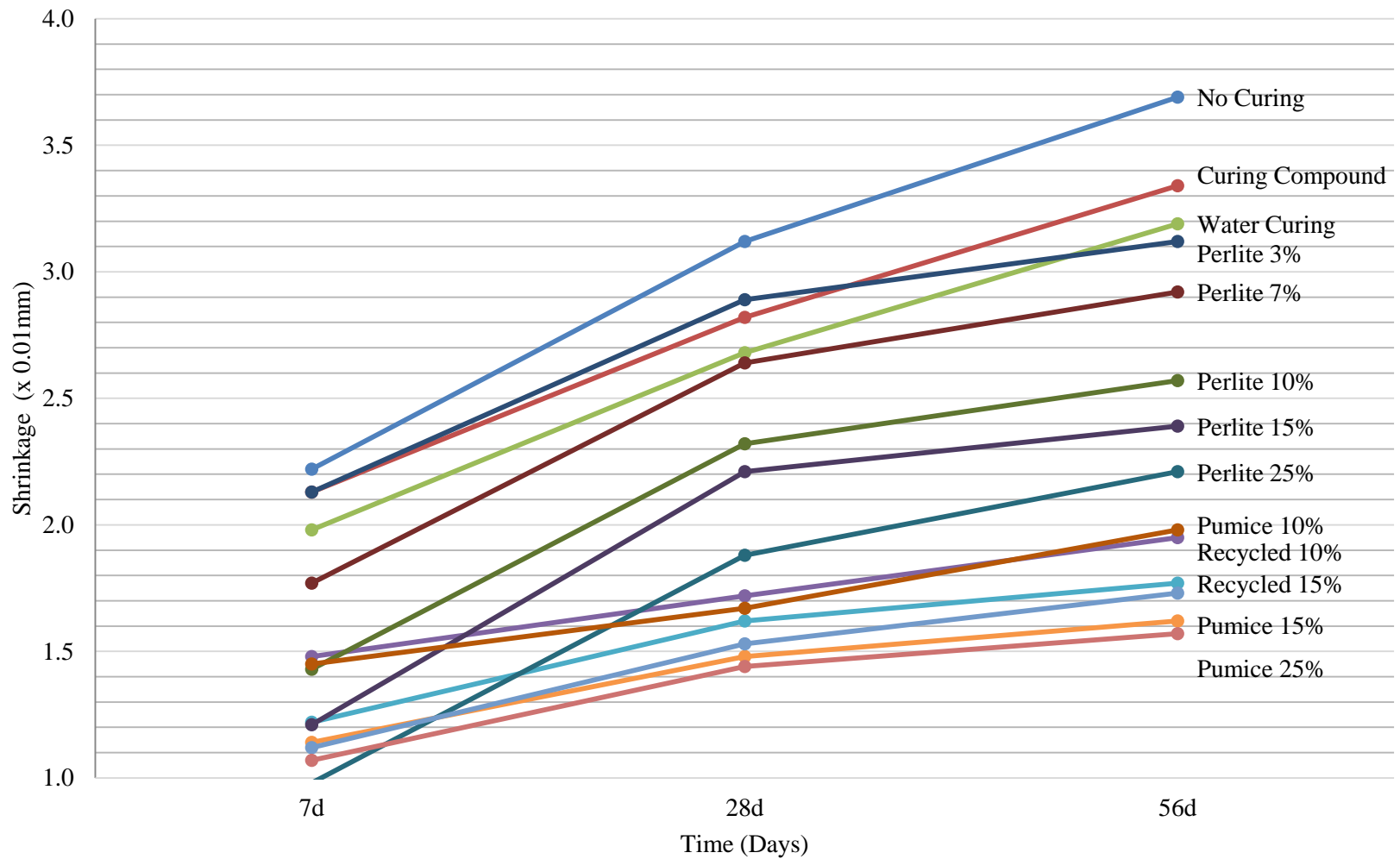
Figure 4-10: Results of Shrinkage test for different concrete mixtures

4.3.2 RAPID CHLORIDE PERMEABILITY TEST (RCPT)

The results of RCPT are listed in table 4-3 and are illustrated in figure 4-11. As can be seen in figure 4-11, the passing charges ranged from 1202 to 2598 coulombs. The case of lowest passing charges was that of concrete made with conventional dolomite aggregates, full curing followed by curing compound. This can be mainly because of the high unit weight/density of conventional aggregate mixtures in comparison to the internally cured ones because of their decreased densities due to aggregate replacement. Another factor is the amount of cracking inside the concrete section itself. Results of RCPT strongly assures on the issue of curing. All cured specimens, whether internally or externally cured have shown decreasing penetrability through the 28 and 56 days testing. Only the no curing specimen showed an increased penetrability as it passed 1588 charges in 56 days increasing by 24 units than the 28 days results. Conventional mixtures' passing charges, on average, decreased by 29 charges from 28 to 56 days. Perlite mixtures had the most decreased passing charges with 63 less passing charges from 56 to 28 days. Pumice showed the worst performance, this can be explained because of the high porosity of this kind of aggregate. It is concluded that unit weight, curing, interlocking (voids percentage), and aggregate porosity are the main factors that affect the penetrability of the concrete section.
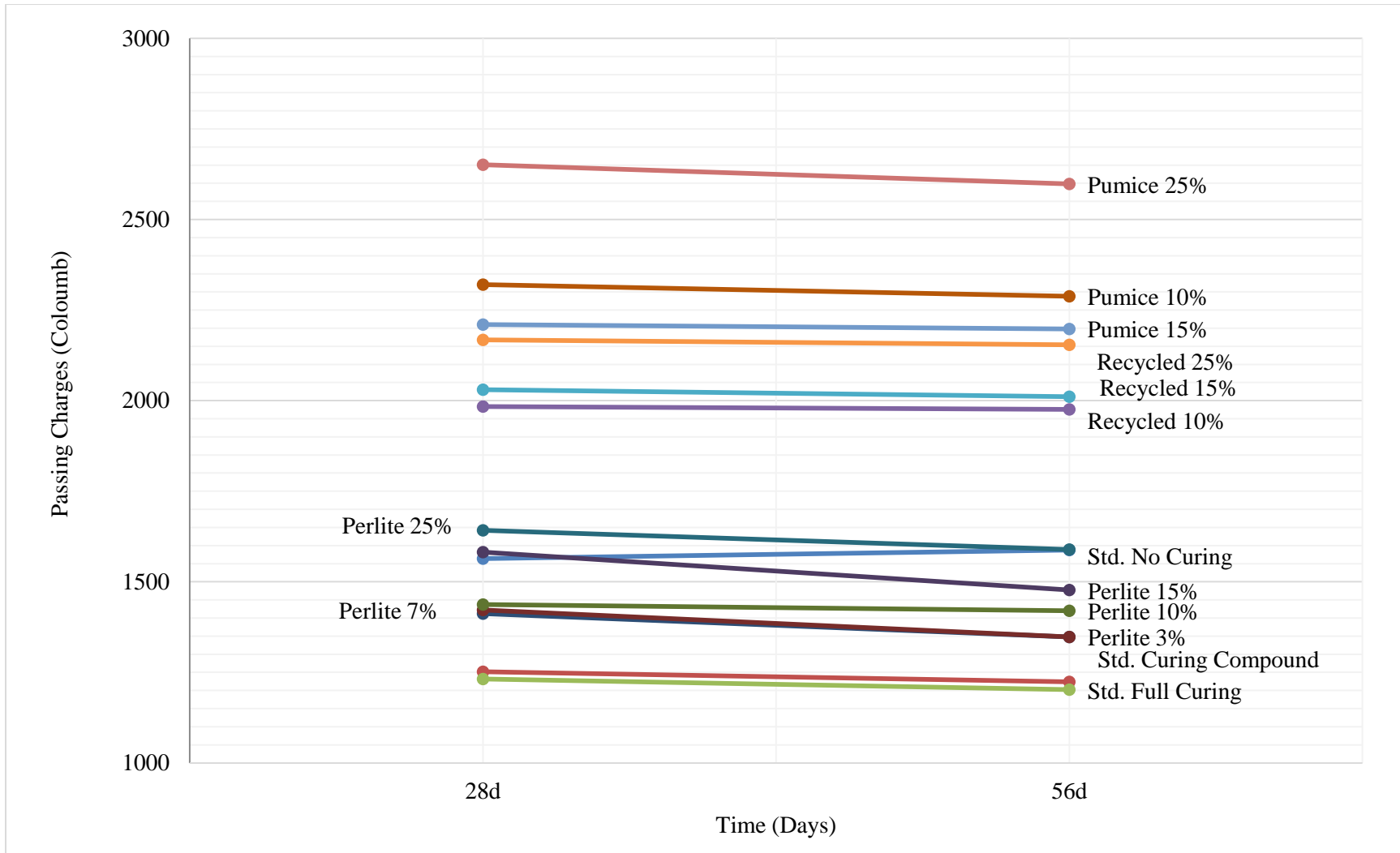
Figure 4-11: Results of Rapid Chloride Permeability Test (RCPT)

4.3.3 ABRASION TEST

The Results of Abrasion Test are listed in table 4-3 and are illustrated in Figure 4-12. As can be seen in figure 4-12, the Abrasion values range from 1.3 to 3.44 mm of lost thickness. Conventional concrete specimens have demonstrated the best abrasion performance as it lost only 1.6 mm on average that is the least amount, followed by perlite specimens with 2.36 mm, then recycled concrete specimens with 2.83mm. Pumice was at the worst at abrasion resistance, averaging almost 3mm of lost thickness. This behavior is explained through the abrasion resistance of the aggregates themselves. Dispersion plays an important role here. Perlite demonstrated similar behavior to the conventional specimens because of the well dispersion of perlite throughout the section, in contrast with both the Recycled concrete aggregates and the pumice specimens. Aging may also be a reason for the poor abrasion performance of specimens with recycled concrete aggregates. This recycled concrete dates back to the 60's, which is the time of construction of the famous AUC science building. Generally, abrasion was slightly affected with aggregates replacements, specifically the coarser replacements.
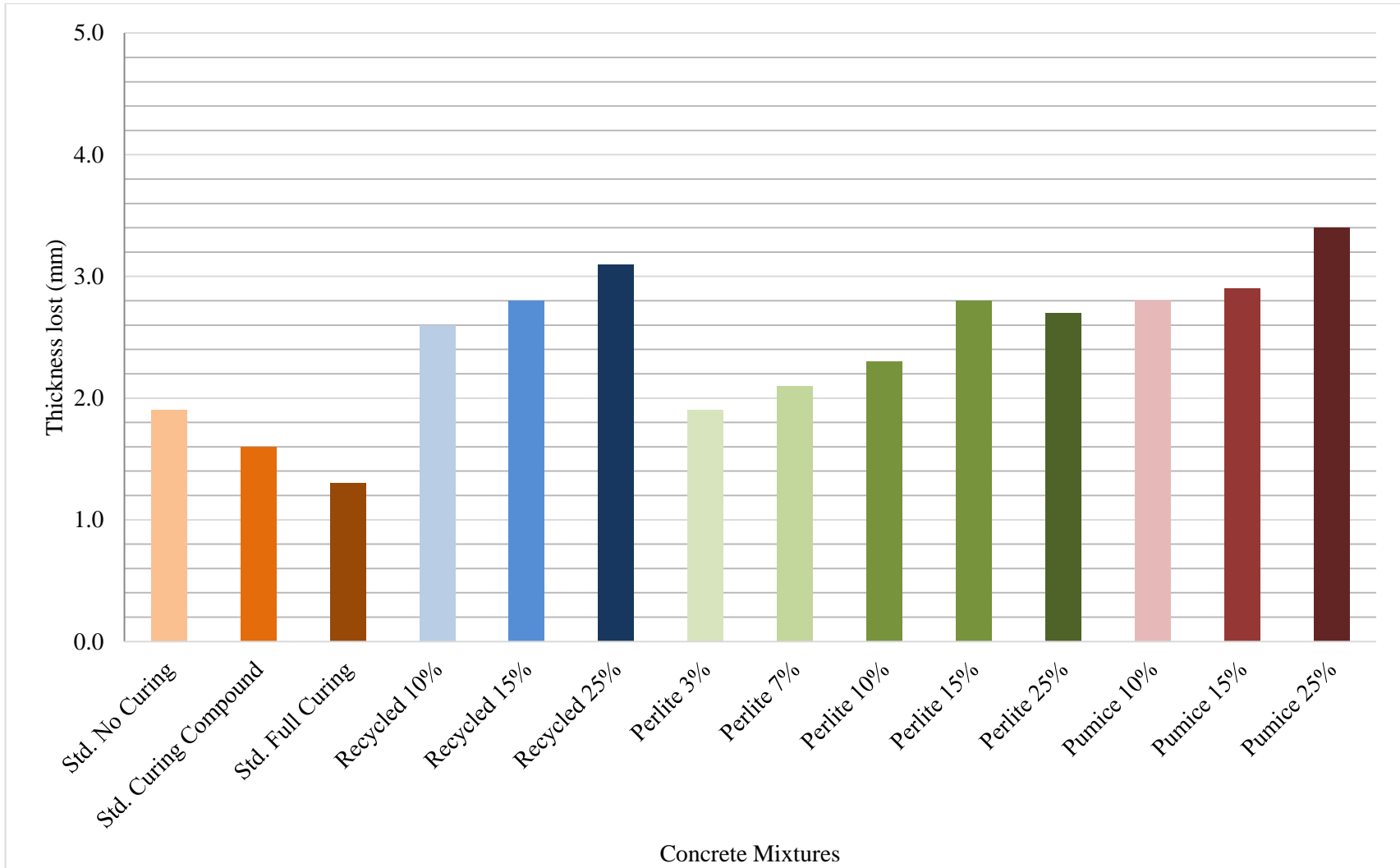
Figure 4-12: Results of Abrasion Test

CHAPTER 5

PRELIMINARY FEASIBILITY ANALYSIS

The feasibility of internal curing technology is directly related to its technical properties and long term performance. Its economic feasibility is determined in the light of a complexity of parameters, which are summarized in this section.

5.1 AVAILABILITY

Perlite aggregates are manufactured locally. Perlite is widely available in areas of Burj Al Arab, Alexandria and Atakkah, Suez. Perlite is widely used in other industries and in producing lightweight concrete. Egypt produces almost 250 Km^3 of perlite annually, only 10% is used for concrete purposes. Needless to say, internal curing is not one of these concrete applications.

The annual amount of recycled aggregates from destroyed structures is assessed as 2% of aggregate volume of existing concrete. Obviously, areas of normal disasters or clashes can have higher percent than this one. Moreover, the assessed measure of rejected fresh concrete created can be as high as 3%. The last is advantageous since it incorporates insignificant measure of contaminants (Abou-Zeid et. al, 1998).

5.2 SPECIAL EQUIPMENT

The only special equipment used may be crusher for recycled concrete aggregates production and special storage area with sprinklers for pre-wetting of aggregates. One challenge that faces the concrete crushing is the impurities problem. The overall efficiency of the crushing process cannot be separated from the handling of impurities present in demolished concrete (e.g. paints or reinforcing steel). This matter can become

a cumbersome one particularly in residential building demolition (Abou-Zeid, et al., 1998). However, advanced systems are now established for purposes of separation and sorting. As for the pre-wetting of the aggregates, at the ready-mix plant, a separate bin may be used for the aggregates or they may be kept in (sprinkled) piles. The time required for sprinkling a new pile prior its use in concrete is dependent on the application rate of the water and the aggregates' absorption characteristics (Villareal, 2008). Villareal also suggests a system to save more water by recycling the excess runoff water back into the sprinkler system.

Figure 5-1: Simple recycled concrete aggregate crusher (Eagle Crushers, 2016)

5.3 TRANSPORTATION

The feasibility of the internally cured concrete is exceedingly affected by transportation costs. In roads construction, transportation expense can be decisive. This is likewise the case for projects in centers of urban zones where transportation and access to destinations is difficult and the utilization of site accessible concrete is thus considered.

Likewise, transporting extra water for curing to versatile locales could be very costly in a few nations like Egypt. In coming years, and after relative political stability, Egypt is undergoing numerous numbers of gigantic projects; New Capital, New Suez canal, Port Saied, and national roads project; to name only some. Most of these projects are in mobile areas to encourage stretching the outskirts of the country to decrease dense populations in the Cairo and Delta areas. This comes with its drawbacks of transportation of raw materials like concrete and water. Internally cured concrete would save a considerable amounts of water transported to these mobile sites.

5.4 WATER

Water scarcity threat has been a global center of focus for many decades in areas with no fresh water access, unlike Egypt. However, this issue has been raised in Egypt from over 30 years ago coinciding with many Nile river countries building dams to secure its share from fresh water. Grand Ethiopian renaissance dam, commonly known as Al Nahda dam, which is expected to operate by July 2017 is one of the most critical challenges facing Egyptians. This dam is forecasted to decrease Egypt's share by almost 8-10 Billion cubic meters of water, and almost 40% less effect on electricity production throughout the period to fill the tanks (Elbaradei, 2016). Based upon these facts, Egypt should adapt to these changes by enforcing some strict rules and encouraging other water saving ideas and activities. Internal curing decreases water consumption drastically, and shall wisely save water from being randomly and uncontrollably splashed over concrete.

Figure 5-2: Picture showing construction of Ethiopian Grand Dam (Daily news Egypt, 2014)

5.5 SIMPLIFIED LIFE CYCLE COST ANALYSIS

A Life Cycle Cost Analysis (LCCA) is done when there is a need to assess and compare the monetary performance of competing design and maintenance alternatives. A LCCA was led to survey the life-cycle costs of conventional concrete versus internally cured concrete, for which various sorts of exercises may be booked at diverse focuses in time, for instance: periodical assessments, required maintenance and repairs, and also replacement; figure 5-2. This is typically accomplished by ascertaining the Present Value Life-Cycle Costs (PVLCC) of the options over a given time period (Hawk H., 2003):

$$PVLCC = C_0 + \sum_{t=1}^{T} \frac{C_i}{(1+r)^t} - \frac{R_v}{(1+r)^T}$$

[Equation 4]
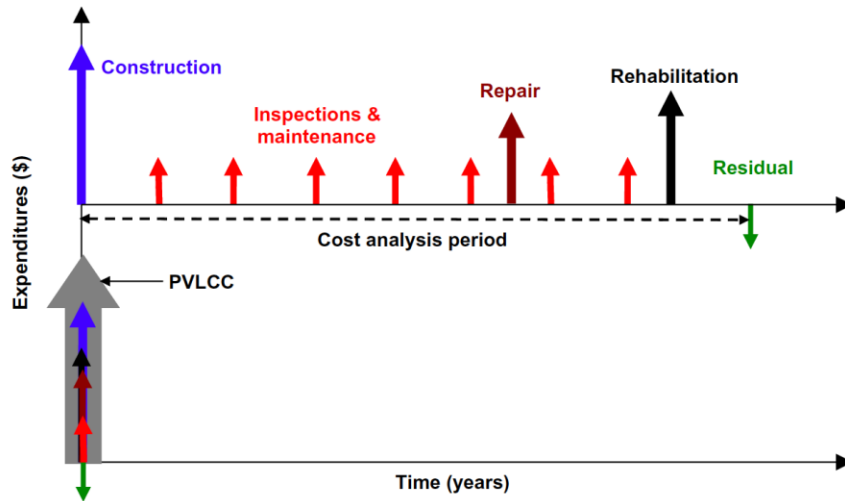
Figure 5-3: Expenditures over life cycle costs of concrete structures (Cusson et al., 2010)

where C_0 is the initial construction cost; C_i is the ith expense at given time t (years) after construction; r is the discount rate; T is the analysis period (years); and R_v is the residual estimation of the option toward the end of the analysis period. In this study, the analysis period was set to 60 years for all cases, with no discount rate for most conservative scenario. The direct costs incurred usually include initial construction costs and other costs associated with the maintenance activities. In this case, the cost of the in-place cost of concrete was only included excluding all other related works like reinforcement and formwork. Also, excluded the markups of the concrete supplier. The cost of concrete will depend on many factors, such as the type and quantity of cement, aggregates, water and admixtures used in the concrete mixture, and availability. In this study, difference between normal concrete (NC), High performance concrete (HPC) and internally cured concrete (IC) will be carried out. Table 5-1 shows the different quantities and costs for each mixture.

Table 5-1: Estimated Cost of different concrete mixtures

Material	NC - C40			HPC - C55			ICC - 10% Perlite - C55		
	Quantity	Unit price	Cost	Quantity	Unit price	Cost	Quantity	Unit price	Cost
Cement (kg)	400	0.6	240	450	0.6	270	450	0.6	270
Coarse Aggregates (kg)	1,060	0.0	47.7	1,050	0.0	47.3	1,050	0.0	47.3
Fine Aggregates (kg)	790	0.0	14.2	662	0.0	11.9	590	0.0	10.6
Crushed Sand (kg)	112	0.1	5.6	112	0.1	5.6	105	0.1	5.3
Water (L)	172	0.00015	0.026	170	0.00015	0.026	180	0.00015	0.027
Admixture (L)	5	8	40	7.5	8	60	7.5	8	60
Perlite (kg)	-	1.5	-	-	1.5	-	100	1.5	150
Curing Water (L) Including Transportation	200	0.025	5.0	200	0.025	5	-		-
Total (LE/m3)	352			399			543		

The unit cost of HPC (LE 400/m^3) was evaluated to be 13% higher than that of ordinary C-40 concrete (LE 350/m^3), basically because of the increased amount of cement in the mixture. The unit cost of ICC was set to that of HPC in addition to a 35% expansion to represent the cost contrast connected with the procurement and transportation of the lightweight aggregate (with a purchase cost of LE 1,500/m^3) used to substitute a small amount of the ordinary aggregates.

For this situation consider, an arrangement of different maintenance exercises were expected to occur over the life cycles. For normal concrete (NC) for example, destructive (NDT) assessment and protection exercises were planned to happen at regular intervals, while patch repairs were scheduled when 10% and 25% of the concrete surface would be spalled. In this study, replacement was esteemed vital when half of the concrete

surface would be spalled. After replacement, it was expected that the concrete would be reconstructed with a similar initial construction cost considering inflation rate. Concrete thickness was assumed at 200mm to represent figures in m^2. Results are shown in table 5-2 below:

Table 5-2: Life Cycle Cost Analysis of different concrete mixtures

Cost	NC – C40	HPC – C55	ICC - C55
Initial Cost (LE/m^2)	71	80	109
PVLCC @60Y (LE/m^2)	1,218	1,035	927

The above table shows the difference between the 3 concrete types and the corresponding initial and Present Value Life-Cycle Costs. It's obvious that the ICC has less frequent check, protection, maintenance and replacement times than the HPC and NC respectively. Costs of maintenance activities were estimated from average market prices. Over a 60-year examination period, the PVLCC for the normal concrete deck is the most noteworthy at LE 1,218/m^2, which is basically because of the shorter service life and the more incessant maintenance and replacement exercises. The HPC deck (no internal curing) diminished this cost by 18%, predominantly because of the more extended service life. The ICC deck further lessened the PVLCC down to LE 927/m^2, which is 31% less costly than the NC deck, or 12% less costly than the HPC deck because of the utilization of internal curing.
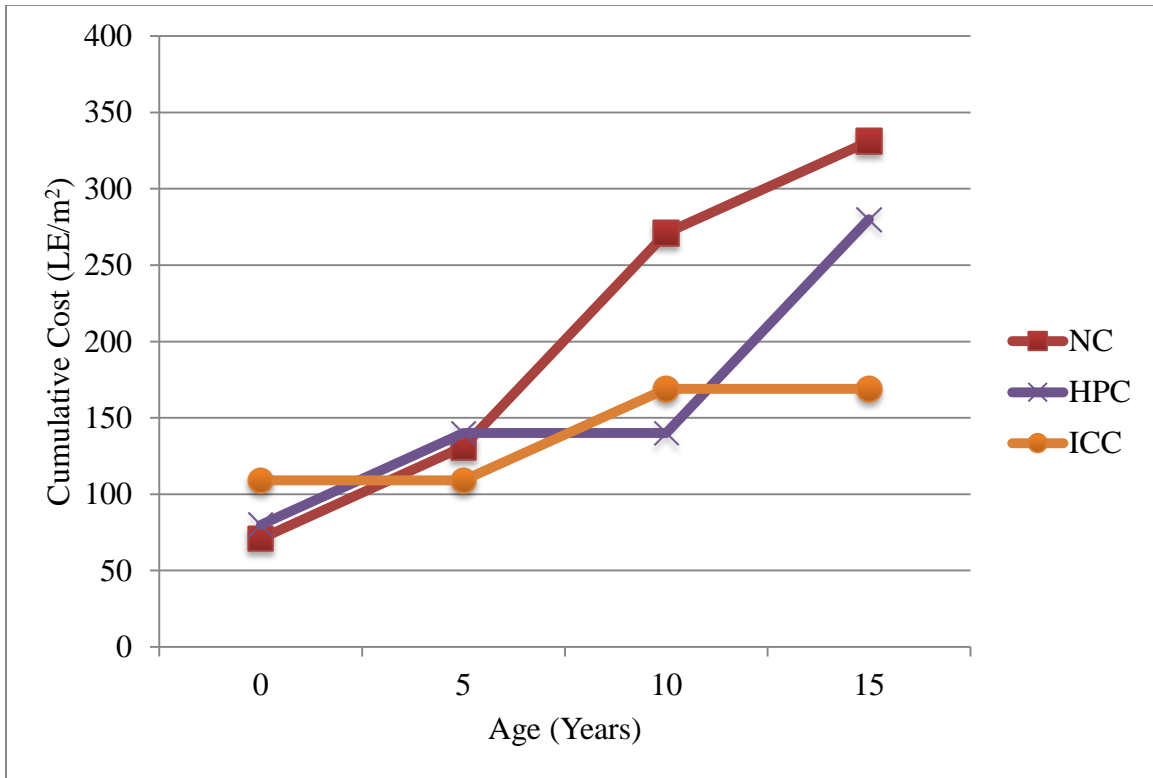
Figure 5-4: Cumulative costs of different concrete mixtures over time in years

It can be concluded that contrasted with normal concrete, internally cured concrete provided an extra 40 years of service life. This is because of the utilization of lower water–cement ratio (expanding strength and diminishing permeability) joined with the utilization of internal curing (both lessening porousness and danger of cracking). The life-cycle cost of a bridge deck can be significantly lessened when utilizing high performance concrete over ordinary concrete, particularly with internal curing. This can be ascribed to less maintenance exercises and a more extended serviceability. Figure 5-4 demonstrates the present value cumulative costs incurred over the first 15 years of the 60-year period for the three concrete deck options. It is clearly demonstrated that the higher initial investment in the ICC deck, contrasted with the NC deck, can be counterbalanced in just 5 years and can counterbalance the HPC cost in just 10 years, mainly because of

the lower maintenance costs connected with ICC. Full analysis table incorporating all maintenance and repair costs is attached at Appendix A.

5.6 CASE STUDY – EGYPT'S NEW CAPITAL

In this section, a simple cost assessment of internally cured concrete is presented for a major construction project in Egypt; the new Capital. The proposed new capital of Egypt is a project announced by Egyptian housing minister Mostafa Madbouly at the Egypt Economic Development Conference on 13 March 2015 (Al Jazeera English, 2015). The new city is to be located 45 kilometers east of Cairo. According to the plans, the city would become the new administrative and financial capital of Egypt, housing the main government departments and ministries, as well as foreign embassies. On 700 square kilometers total area, it would have a population of five million people, though it is estimated that the figure could rise to seven million (BBC News, 2015).

Figure 5-5: Location of New Capital (The Capital Website, 2015)

The study is based on the construction of the infrastructure of this gigantic development, mainly water and power plants, roads and bridges, utilities and others. Data were obtained from many sources, mainly market studies and New Capital website. This assessment is based on certain assumptions. Needless to say, the validity of these assumptions is to be questioned and perhaps modified in the light of the project nature and other prevailing parameters.

Table 5-3: Assumptions of New Capital Infrastructure, (The Capital Website, 2015)

Item	Quantity
Gross Land Area	700 km^2
Land Available for Development	490 km^2
Expected Population	5,000,000
Residential Districts	21
Airport Area	16 km^2
Roads & Bridges	140 km^2

This study primarily focuses on the infrastructure construction of the new capital, in specific the ones using High Performance Concrete (HPC) in construction. The above table shows data revealed from the authorities or companies concerned with the project. Assumptions were also made to estimate future market demand of concrete and other construction materials. Market studies at the time of the announcement of the project, estimated that the project in its first phase would cost $45bn and takes up to seven years to complete (Al-Jazeera, 2015). Also, earlier 2016, the government agreed to assign administrative infrastructure of the new Capotal work at LE 4 billion (youm 7, 2016).

Figure 5-6: New Capital prototype unveiled in EEDC 2015 (Al-Jazeera, 2015).

The case study will focus on the advantages incorporated upon using Internally Cured Concrete (ICC) versus using conventional high performance concrete (HPC). The aspects examined are mainly economical and environmental. The economical aspect, carried out in the previous section, is represented through the costs saved in the entire service life of a certain structure and the costs saved in maintenance and repairs. Environmental aspect is mainly the water saved during the conventional water curing through surface splashing. Assuming a service life of 60 years, and incorporating all maintenance and repair costs, previous section concluded a cost saving of LE 1,965 per cubic meter of concrete between HPC and ICC. Also water saving of 192 Liters per cubic meter of concrete including mixing and curing water. Market studies and analysis estimated additional 35 Million cubic meters of concrete dedicated for the construction of first stage of the new Capital (EIU, 2015). It can be assumed that 20% of this quantity is

dedicated for infrastructure and utilities, summing 7 Million cubic meters. Following are the carried out calculations:

Table 5-4: Economical Savings from incorporating ICC in New Capital

Concrete Quantity for Infrastructure	7,000,000 m^3
Cost Saving per m^3	LE 1,455
Total Cost Saving	LE 10.2 Billion

Results listed in table 5-4 conclude that the use of internally cured concrete for the infrastructure projects as an alternative to the conventional concrete can save up to LE 10.2 billion, or alternatively, 1.15 billion US dollars which is almost 3% from the entire project budget.

Table 5-5: Water Savings from using ICC in New Capital Infrastructure

Concrete Quantity for Infrastructure	7,000,000 m^3
Water Saving per m^3	0.195 m^3
Total Water Saving	1.365 Million m^3

Results listed in table 5-5 reveal environmental aspect of adapting ICC technology in the new capital. Almost 1.5 Million cubic meters of water are saved from being randomly and uncontrollably splashed over concrete structures for curing.

Both cost and water saving assert on the potential of adapting the technology of internally cured concrete for infrastructure uses. The ICC, if used in the new capital, can save up to 3% of total project budget and almost 1.5 Million cubic meters of fresh water over the 7 years of the first stage of the project.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In this chapter, an overall summary as concluding remarks of this study as well as recommendations for applicators and future research work are provided.

6.1 CONCLUSIONS

In the light of scope, types and dosages of materials investigated as well as other experimental parameters and variability associated with this work, the following key conclusions can be warranted:

1. The concrete mixtures incorporating saturated lightweight and recycled concrete aggregates demonstrate increase in slump values that increases with the increase of pre-wetted aggregate content. The slump increase reflects an overall enhanced workability of Internally cured concrete

2. Incorporating pre-wetted lightweight and recycled concrete aggregates led to a slight increase in air content. Air content increased with higher replacement dosages possibly due to the porosity nature of lightweight and recycled aggregates. However, such increase is considered insignificant.

3. Lightweight and recycled concrete aggregates mixtures possess slightly less unit weight compared to conventional concrete mixtures.

4. Compressive strength of concrete showed to be clearly affected by curing mode, tests reveal highest values for full curing followed by ones cured by curing compound and least values for non-cured specimens.

5. Compressive strength of internally cured concrete was lower than conventional concrete made with conventional aggregates. The drop in strength was higher as the lightweight and recycled concrete aggregates dosages increased.

6. Aggregate type, dosage and dispersion are three principal factors that affect compressive strength of internally cured concrete.

7. Internally cured concrete yielded similar strength development from 7-28 days compared to conventional concrete. However, the 28-56 days strength development is significantly higher for internally cured concrete, due to the enhanced hydration process that maintained the relative humidity levels in the internally cured concrete mixtures.

8. Flexural strength results have fairly comparable patterns to those of compressive strength as increased dosages yield lower strength. Recycled aggregates concrete promoted flexural strength that is comparative or surpassing conventional mixtures. Possibly due to the Interfacial Transition Zone (ITZ) between aggregate surface and concrete paste, which enhanced internal properties and caused better aggregate-paste interlocking.

9. Flexural-compressive strength ratio for mixtures of internally cured concrete is higher than mixtures of conventional concrete. Also possibly due to to the Interfacial Transition Zone (ITZ) between aggregate surface and concrete paste.

10. Internally cured concrete mixtures had critical impact in decreasing shrinkage and shrinkage cracking. Such reduction was higher after increasing the replacement dosages of lightweight and recycled concrete aggregates.

11. Rapid chloride permeability test (RCPT) reveal that concrete's unit weight, curing mode and aggregate porosity are the main factors that affect the penetrability of the concrete section.

12. RCPT also revealed that internally cured concrete yielded slightly lower performance compared to conventional concrete. However, Internally cured mixtures yielded significantly better improvement from 56-28 days.

13. Abrasion resistance of internally cured concrete is similar to that of conventional concrete. This was the case for mixtures made with both lightweight and recycled concrete aggregates.

14. Internally cured concrete can save considerable amounts of water transported specially to mobile areas. This is of high importance since Egypt is undergoing numerous number of gigantic projects in areas of not steadily fresh water supply.

15. As Egypt faces a water scarcity challenge, internally cured concrete decreases water consumption drastically and saves water from being randomly and uncontrollably splashed on concrete

16. A simple Life-Cycle Cost Analysis reveals that internally cured concrete saves up to 31% of cost throughout its service life compared to conventional concrete

17. The higher initial investment of internally cured concrete can be counterbalanced because of the lower maintenance costs associated.

18. Egypt, if utilizes internally cured concrete in the New Capital Project for example, can save up to LE 10.2 Billion and 1.5 Million cubic meters of water throughout the duration of the first stage of the project on Infrastructure construction & maintenance.

6.2 RECOMMENDATIONS FOR FUTURE WORK

This investigation pinpoints specific areas where recommendations can be made and further studies to be conducted including the following:

1. Other types of lightweight aggregates need to be examined and in different dosages to compare to current tested ones

2. The influence of age of crushing the aggregates and storage time need to be further examined.

3. Nature of interference between lightweight aggregates and other cementitious binding materials (i.e. slag, silica fumes, etc.) shall be further examined

4. Fire resistance should be tested to assess performance of internally cured concrete in cases of increased temperatures.

5. Further durability tests are needed such as freezing and thawing, scaling, chemical durability and water permeability.

6. It is recommended that field trials be performed with instrumentation, documentation and monitoring and on extended periods of time to be able to quantify benefits of technology to enable it to be more commonly used.

6.3 RECOMMENDATIONS FOR APPLICATORS

Methodologies for executing internal curing underway are basically the same as those utilized for delivering lightweight concretes for over 50 years.

1. At the ready-mix plant, a separate bin may be used for the lightweight aggregates or could be kept in sprinkled piles at the site, The time required for sprinkling a new pile before use in concrete is dependent on the application rate of the water and the aggregate's absorption characteristics

2. As with any aggregate being incorporated into a concrete, the moisture content and absorption capacity of the LWA must be known prior to the final proportioning of the concrete

3. Crushing of concrete to be used as recycled concrete aggregates must follow a standard procedure of crushing, removing impurities and finally grading.

4. Mixing saturated aggregates with other ingredients of concrete follows the same standard procedure of mixing and batching of ready-mix concrete.

5. Applicators must be aware that they are dealing with a material that has a different nature and characteristics than conventional concrete. Handling time must be controlled, so that the lightweight aggregates don't lose its water before setting. Also, pumping should be something well handled to prevent segregation or separation of lightweight aggregates from concrete (common defect in ultra lightweight aggregates)

6. Concrete finishing is basically the same as that of the conventional concrete.

REFERENCES

Abou-Zeid, M. N., Khandil, A. A. and El-Saaran, I. M. "Recycled Concrete: Myth or Reality". 8th International Colloquium on Structural and Geotechnical Engineering, Ain Shams University, Proceedings, December 1998.

Abou-Zeid, M. N., Ismael, M. and Hammam, A. " Incorporation of lightweight and recycled aggregates for concrete curing". CSCE Annual Conference, 2015

ACI 213R-03: Guide for Structural Lightweight-Aggregate Concrete. ACI Committee 213. American Concrete Institute, Farmington Hills, Michigan, 2012.

ACI 308R-01: Guide to Curing Concrete. ACI Committee 308. American Concrete Institute, Farmington Hills, Michigan, 2015.

Aitcin, Pierre-Claude, and Barbara B. Stern. High-performance Concrete. London: E&FN Spon, 1998.

Alberty, R., & Daniels, F. Physical Chemistry. New York: John Wiley & Sons, 1980

Al Jazeera English. "Egypt Plans New Capital Adjacent to Cairo." 14 Mar. 2015. <http://www.aljazeera.com/news/2015/03/egypt-plans-capitaladjacent-cairo 150314014400946.html>.

Al Wafd. Report: 40% of Bridges Egypt at Risk and in Danger of Collapse. 8 Feb. 2016. <http://alwafd.org/>.

Babcock, Anthony, and Peter Taylor., IMPACTS OF INTERNAL CURING ON CONCRETE PROPERTIES: Literature Review. Iowa Highway Research Board, 2015.

BBC News. "Egypt Unveils Plans to Build New Capital East of Cairo " BBC News. 13 Mar. 2015. <http://www.bbc.com/news/business-31874886>.

Bediako, Mark, J. T. Kevern, and Eric Opoku Amankwah, Effect of Curing Environment on the Strength Properties of Cement and Cement Extenders. Scientific Research Publishing Inc., 2015.

Bentur, A., Igarishi, S., & Kovler, K., Control of Autogenous Stresses and Cracking in High Strength Concretes. Proceedings of the 5th International Symposium on High Strength/High Performance Concrete, Sandefjord, 1999.

Bentz, D.P., "Influence of Internal Curing Using Lightweight Aggregates on Interfacial Transition Zone Percolation and Chloride Ingress in Mortars," Cement and Concrete Composites, 2009.

Bentz, Dale P., Transport Properties and Durability of Concrete Literature Review and Research Plan. McLean, VA: U.S. Dept. of Transportation, Federal Highway Administration, 2002.

Bentz, Dale P., Pietro Lura, and John W. Roberts. Mixture Proportioning for Internal Curing. Concrete International, 2005.

Bentz, Dale P., and W. Weiss. Internal Curing: A 2010 State-of-the-art Review. Gaithersburg, MD: U.S. Dept. of Commerce, National Institute of Standards and Technology, 2011.

Bentz, D., Hansen, K., Madsen, H., Vallee, F., & Griesel, E. Drying/Hydration in Cement Pastes during Curing. Materials and Structures, 2001.

Bentz, D., Lura, P., & Roberts, J. Mixture Proportioning for Internal Curing. Concrete International, 2005.

Bentz, D., Snyder, K., & Peltz, M., Doubling the Service Life of Concrete Structures. II: Performance of Nanoscale Viscosity Modifiers in Mortars. Cement and Concrete Composites, 2010.

Bremner, T., & Ries, J., Stephen J. Hayde: Father of the Lightweight Concrete Industry. Concrete International , 2009

Castro, J., Keiser, L., Golias, M., & Weiss, W., Absorption and Desorption of Fine Lightweight Aggregate for Applications to Internally Cured Concrete Mixtures. Cement and Concrete Composites, 2011.

Cusson, D., & Hoogeveen, T., Internal Curing of High-Performance Concrete with Pre-soaked Lightweight Aggregate Sand for Prevention of Autogenous Shrinkage Cracking. Cement and Concrete Research, 2008

Cusson, D., Lounis, Z., & Daigle, L., Benefits of Internal Curing on Service Life and Life-Cycle Cost of High-Performance Concrete Bridge Decks - A Case Study. Cement and Concrete Composites, 2010

Daily News Egypt. "Shoukry in Addis Ababa for Talks over Grand Ethiopian Renaissance Dam, 2014 <http://www.dailynewsegypt.com/2014/11/02/shoukry addisababa-talks-grandethiopian-renaissance-dam/>.

Di Bella, C., Schlitter, J., & Weiss, W., Construction Documentation of Bloomington Bridges, 2010.

Eagle Crushers. 2016. <http://www.eaglecrusher.com/>.

EIU: The Economist Intelligence Unit. "Egypt: Annual Report". Mar. 2015. <http://country.eiu.com/egypt>.

ElBaradei, Sherine. "Ethiopia's Renaissance Dam: What Options Are Left for Egypt?" Ahram Online. 11 Mar. 2016.

Foster Supply. 2012. <http://www.fostersupply.com>.

Friggle, T., & Reeves, D. Internal Curing of Concrete Paving: Laboratory and Field Experience. In D. Bentz, & B. Mohr (Ed.), Internal Curing of High Performance Concretes: Laboratory and Field Experiences Farmington Hills: American Concrete Institute, 2008.

GARBLT. "National Roads Project 2015." - General Authority For Roads, Bridges & Land Transport. Web. 04 Nov. 2015.

Golias, M., The Use of Soy Methyl Ester-Polystyrene Sealants and Internal Curing to Enhance Concrete Durability, M.S. Thesis. West Lafayette: Purdue University, 2010.

Gonnerman HF, Shuman EC., Flexure and tension tests of plain concrete. Major series 171, 209 and 210. Report of the Director of Research. Port. Cem. Assoc., 1928.

Hammer, T.A., Bjontegaard, O., and Sellevold, E.J., Internal Curing - Role of Absorbed Water in Aggregates, ACI SP-218, High Performance Structural Lightweight Concrete, Eds. J.P. Ries and T.A. Holm, 2004.

Halamickova, P., Detwiler, R., Bentz, D., & Garboczi, E., Water Permeability and Chloride Ion Diffusion in Portland Cement Mortars: Relationship to Sand Content and Critical Pore Diameter. Cement and Concrete Research, 1995.

Hawk, H. Life-Cycle Cost Analysis. Washington: Transportation Research Board. NCHRP Report 483, 2003.

Henkensiefken, R., Briatka, P., Bentz, D., Nantung, T., & Weiss, J. Plastic Shrinkage Cracking in Internally Cured Mixtures Made with Pre-wetted Lightweight Aggregate. Concrete International, 2010.

Henkensiefken, R., Castro, J., Bentz, D., Nantung, T., & Weiss, J. Water Absorption in Internally Cured Mortar Made with Water-Filled Lightweight Aggregate. Cement and Concrete Research, 2009.

Henkensiefken, R., Nantung, T., & Weiss, W., Internal Curing - From the Laboratory to Implementation. International Bridge Conference, 2009

Henkensiefken, R., Nantung, T, and Weiss, J. Reducing Restrained Shrinkage Cracking in Concrete: Examining the Behavior of Self-Curing Concrete Made using Different Volumes of Saturated Lightweight Aggregate, 2008.

Holm, T., Bremner, T., & Newman, J. Lightweight Aggregate Concrete Subject toSevere Weathering. Concrete International , 1984.

Huo, Sharon Xiaoming and Wong, Ling Ung, Early-Age Shrinkage of HPC Decks Under Different Curing Methods. Http://ascelibrary.org/doi/ Cookeville, TN: ASCE, 2000.

Joseph, Basil. Studies On Properties Of Self-Curing Concrete Using Polyethylene Glycol. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 2016.

Kim, H., & Bentz, D., Internal Curing with Crushed Returned Concrete Aggregates. NRMCA Technology Forum: Focus on Sustainable Development, 2008.

Klieger, Paul., Curing Requirements for Scale Resistance of Concrete. Chicago: Portland Cement Association, 1957.

Kovler, K., and Ole Mejlhede. Jensen. Internal Curing of Concrete: State of the Art Report of RILEM Technical Committee TC 196-ICC--"Internal Curing of Concrete" Bagneux, France: RILEM Publications, 2007.

Lamond, Joseph F., and J. H. Pielert. Significance of Tests and Properties of Concrete and Concrete-making Materials. Philadelphia, PA: ASTM, 2006.

Lopez, M., Kahn, L., & Kurtis, K., Effect of Internally Stored Water on Creep of High Performance Concrete. ACI Materials Journal , 2008.

Lura, P., Couch, J., Jensen, O., & Weiss, W., Early-Age Acoustic Emission Measurements in Hydrating Cement Paste: Evidence for Cavitation during

Solidification Due to Self-Desiccation. Cement and Concrete Research , accepted for publication, 2009.

Neville, A. M., Properties of Concrete, 4th Edition, Wiley, 1996

NPCA: NATIONAL PRECAST CONCRETE ASSOCIATION. Curing Wet-Cast Precast Concrete, 2013.

Parrott, L. J.; Killoh, D. C.; and Patel, R. G., "Cement Hydration under Partially Saturated Conditions," Proceedings, 8th Congress on Chemistry of Cement, Rio de Janeiro, V. 3, 1986.

Philleo, R. Concrete Science and Reality. In J. Skalny, & S. Mindess (Eds.), Materials Science of Concrete II. Westerville, OH: American Ceramic Society, 1991.

Powers, T., Copeland, L., & Mann, H., Capillary Continuity or Discontinuity in Cement Pastes. The Research Bulletin of the Portland Cement Association , 1959.

Pyc, W., Caldarone, M., Broton, D., & Reeves, D., Internal Curing Study with Intermediate Lightweight Aggregates. In D. Bentz, & B. Mohr (Ed.), Internal Curing of High-Performance Concretes: Laboratory and Field Experiences. Farmington Hills: American Concrete Institute, 2008.

Raoufi, K., Schlitter, J., Bentz, D., & Weiss, J., Parametric Assessment of Stress Development and Cracking in Internally-cured Restrained Mortars Experiencing Autogenous Deformations and Thermal Loading. Cement and Concrete Composites, 2012.

Shah, S., Weiss, W., & Yang, W., Shrinkage Cracking - Can It Be Prevented? Concrete International, 1998.

Shah, S., & Weiss, W., High Strength Concrete: Strength, Permeability, anCracking. Proceedings of the PCI/FHWA International Symposium on High   Performance Concrete, Orlando, 2000.

Shin, K., Bucher, B., & Weiss, W. The Role of Low Stiffness Aggregate Particles on   the Restrained Shrinkage Cracking Behavior of Mortar. ASCE Journal of Materials in Civil Engineering, 2011.

Spears, R.E., "The 80% Solution to Inadequate Curing Problems," Concrete International, V. 5, No. 4, Apr., 1983.

Standard Method of Test for Specific Gravity of Hydraulic Cement. Philadelphia, PA: American Society for Testing and Materials, 1964.

Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. West Conshohocken, PA: ASTM International, 2007.

Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. West Conshohocken, PA: ASTM International, 2010.

Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (using 2 in. or Cube Specimens). West Conshohocken, PA: ASTM International, 2011.

Standard Test Method for Density, Relative Density (specific Gravity), and Absorption of Coarse Aggregate. Philadelphia, PA: ASTM International, 2007.

Standard Test Method for Density, Relative Density (specific Gravity), and Absorption of Fine Aggregate. Philadelphia, PA: ASTM International, 2007.

Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage.

Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration: Designation C1202-12. West Conshohocken: ASTM International, 2013.

Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (using a Steel Form Insert). West Conshohocken, PA, 2006.

Standard Test Method for Fineness of Hydraulic Cement by Air Permability Apparatus. West Conshihocken, PA: ASTM International, 2007

Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. West Conshohocken, PA: American Society for Testing and Materials, 2001

Standard Test Method for Slump of Hydraulic-cement Concrete. West Conshohocken, PA: ASTM International, 2015.

Suryakanta. "WHAT ARE THE EFFECTS OF IMPROPER CURING?" CivilBlogOrg. 24 July 2014. <http://civilblog.org/2014/07/25/what-are-the effects-of-improper curing/>.

Taylor, Peter C. Moving Advancements into Practice: Curing. Iowa State U, 2015.

The Capital Cairo. 25 April. 2015. <http://thecapitalcairo.com/>.

Thomas, M., Chloride Diffusion in High-Performance Lightweight Aggregate Concrete. In J. Ries, & T. Holm (Ed.), Theodore Bremner Symposium on High Performance Lightweight Concrete, 2003.

Van Breugel, K., and Lura, P., Effect of Initial Moisture Content and Particle Size Distribution of Lightweight Aggregates on Autogenous Deformation, Proceedings of the 2nd International Symposium on Structural Lightweight Aggregate Concrete, Eds. S. Helland, I. Holand, and S. Smeplass, Kristiansand, Norway, 2000.

Van Breugel, K., & de Vries, H., Mixture Optimization of Low Water/Cement Ratio, High-Strength Concrete in View of Reduction of Autogenous Shrinkage, 1998.

Villareal, V., Internal Curing - Real World Ready Mix Production and Applications: A Practical Approach to Lightweight Modified Concrete. In D.Bentz, & B.Mohr (Ed.), ACI SP-256, Internal Curing of High-Performance Concrete:Laboratory and Field Experiences.Farmington Hills: American Concrete Institute, 2008.

Villarreal, V., & Crocker, D., Better Pavements through Internal Hydration. Concrete International, 2007.

Weber, S., & Reinhardt, H., A Blend of Aggregates to Support Curing of Concrete. In I. Holand, T. Hammer, & F. Fluge (Ed.), Proceedings of the International Symposium on Structural Lightweight Aggregate Concrete, 1995.

Wei, Y., & Hansen, W., Pre-soaked Lightweight Fine Aggregates as Additives for Internal Curing in Concrete. In D. Bentz, & B. Mohr (Ed.), Internal Curing of High-performance concrete, 2008.

Weiss, Jason. "Internal Concrete Curing Presentation". Purdue University. November 19th 2011.<http:/ www.youtube.com/watch?v=Ee0HGlwKvMY>.

Weiss, Jason, Dale Bentz, Anton Schindler, and Pietro Lura. Internal Curing: Constructing More Robust Concrete. Construction Issuees, 2012.

Weiss, Jason. Raoufi, K., Castro, J. "DEVELOPMENT OF INTERNALLY CURED CONCRETE FOR INCREASED SERVICE LIFE". JOINT TRANSPORTATION RESEARCH PROGRAM. FHWA/IN/JTRP-2010/10. Final Report

Weiss, W., Yang, W., & Shah, S., Factors Influencing Durability and Early-Age Cracking in High Strength Concrete Structures. SP-189-22 High Performance Concrete: Research to Practice   Farmington Hills: American Concrete Institute, 1999.

WHO: World Health Organization Global Status Report on Road Safety 2013: Supporting a Decade of Action. Geneva, 2013.

World Bank. "Egypt Signs $1 Bn Loan with World Bank for Infrastructure Development" Egypt Home. 04 Feb. 2016.

Ye, J., Hu, S., Wang, F., Zhou, Y., Liu, Z., Effect of Pre-wetted Lightweight Aggregate on Internal Relative Humidity and Autogenous Shrinkage of Concrete. Journal of Wuhan University of Technology – Mater, 2006

Youm 7. "The government agrees to assign administrative infrastructure of the capital work at 4 billion pounds". 25 Jan. 2016. <http://www.youm7.com>.

Zhang, M.-H., & Gjorv, O., Permeability of High-strength Lightweight Concrete. ACI Materials Journal , 1991.

Zhutovsky, S., Kovler, K., and Bentur, A., Efficiency of Lightweight Aggregates for Internal Curing of High Strength Concrete to Eliminate Autogenous Shrinkage. Materials and Structures, 2002.

APPENDIX

APPENDIX A: Tables

Table A-1: Detailed Calculations of Present value Life Cycle Cost (PVLCC) of different concrete mixtures, over a comparison period of 60 years

Time	Activity	NC	HPC	ICC
0	Initial Cost	71	80	109
5	NDT	20	20	
	Protection	40	40	
10	NDT	20		20
	Protection	40		40
	Patch Repair	80		
15	NDT	20	20	
	Protection	40	40	
	Patch Repair		80	
20	NDT			20
	Protection			40
	Patch Repair			80
	Replacement	92		
25	NDT	20	20	
	Protection	40	40	
30	NDT	20		20
	Protection	40		40
	Patch Repair	80		
	Replacement		155	
35	NDT	20	20	
	Protection	40	40	
40	NDT			20
	Protection			40
	Patch Repair			80
	Replacement	120		
45	NDT	20	20	
	Protection	40	40	
	Patch Repair		80	
50	NDT	20	20	20
	Protection	40	40	40
	Patch Repair	80		
55	NDT	20	20	20
	Protection	40	40	40
60	Replacement	155	220	298
	PVLCC (LE/m^2)	1,218	1,035	927

APPENDIX B: Data Sheets of Materials

B.1 Cement Data Sheet

LAFARGE CEMENT Egypt

Cement Quality Certificate

Cement Type:	**Type V**
Complies With:	ASTM C150-09

Dispatch Date:	30-Sep-12
Project Name:	Ready Mix

Standard Composition Requirements

Chemical Composition		Test Method C 114-06			Standard Requirements	
		Results				
Silicon Dioxide	SiO_2	21.29	%			
Aluminium Trioxide	Al_2O_3	3.93	%			
Ferric Oxide	Fe_2O_3	4.94	%			
Calcium Oxide	CaO	64.37	%			
Magnesium Oxide	MgO	1.80	%		6.00%	Max.
Sulphate	SO_3	1.99	%		2.30%	Max.
Potassium Oxide	K_2O	0.32	%			
Sodium Oxide	Na_2O	0.35	%			
Chloride	Cl	0.030	%			
Loss On Ignition	LOI	0.74	%		3.00%	Max.
Insoluble Residue	IR	0.32	%		0.75%	Max.
	C3S	61.07				
	C2S	14.99				
	C_3A	2.06	%		5.00%	Max.
	C_4AF	15.03	%			
	C4AF + 2 C3A	19.15	%		25.00%	Max.
	C3S + 4.75 C3A	70.87				

Physical and Mechanical Properties

Compressive Strength	Test method C 109-05		
	Results	Standard Requirements	
3 days	19.3	8.0 N/mm^2	Min.
7 days	26.2	15.0 N/mm^2	Min.
28 days	-	21.0 N/mm^2	Min.

Setting Time	Test Method C191-04			
	Results	Standard Requirements		
Initial Time	160	45	minutes	Min.
Final Time	260	375	minutes	Max.
Standard Consistency	24.80 %			

Soundness - Autoclave Expansion C 151-05
Fineness - Test Method C 204-05

	Results	Standard Requirements
Expansion	0.10	0.8% maxiumum
	Results	
Fineness by Blaine cm^2/g	3130	2600 Cm^2/g minimum

Approved by

For : Ahmed Kamel

B.2 Perlite Data Sheet

The Egyptian Co. For Manufacturing Perlite
الشركة المصرية لصناعة البيرليت

Product Name: construction perlite   **Product code: G5C**

- **Physical Properties**

Color	White
Refractive Index	1.5
Free Moisture, Max.	0.5%
pH	7.5
Specific Gravity	0.32
Bulk Density	85-100kg//m^3
Fusion Point	1260-1343 ^{o}C
Specific Heat	837 J/ kg k
Thermal Conductivity At (24° C)	0.04 -0.06 W/m.k
Softening point	871-1093 ^{o}C

- **Grain Size analysis**

U.S. Sieve No.	Retention (% By weight)				
	8	16	50	100	<100
	50-60	25-30	5-10	5-10	1-5

- **Applications**

  Perlite G5C is ideal for the following applications.
  - Lightweight concrete with sand &Portland cement
  - Lightweight insulating concrete with Portland cement.
  - Lightweight fire proof, insulating plaster with gypsum or Portland cement.
  - Light weight insulating Block.

- **Packing:**
  -          0.1 m3 (100 Litter) Plastic Bag

Product Data Sheet

Product Name construction Perlite

Product code: G5C

Perlite is not a trade name but a generic term for naturally occurring siliceous volcanic rock. The distinguishing feature which sets perlite apart from other volcanic glasses is that when heated to a suitable point in its softening range, it expands four to twenty times its original volume.

This expansion is due to the presence of two to six percent combined water in the crude perlite rock. When quickly heated to above 1600° F (870°C) the crude rock pops in a manner similar to popcorn as the combined water vaporizes and creates countless tiny bubbles in the heat sealed bubbles which account for the amazing light weight and other exceptional physical properties of expanded perlite.

The expansion process also creates one of perlite's most distinguishing characteristics: its white color. While the crude perlite rock may range from transparent to light gray to glossy black, the color of expanded perlite ranges from snowy white to grayish white.

• Chemical Composition wt %

SiO_2	72 – 75 %
Fe_2O_3	0.5 - 0.9 %
Al_2O_3	11 – 14 %
Na_2O	2.8-4.3 %
K_2O	4.8-5.7 %
CaO	0.1-0.8 %
MgO	0.10-0.25 %
H_2O	3.5 - 4.5 %

Head Office: Egypt, 6 October City - Hunaida Center Off. No. 310/5   المكتب الرئيسى : ج.م.ع ، مدينة ٦ أكتوبر ، المحور المركزى ، مركز هنيدة ، مكتب رقم ٣١٠/٥
Tel.:(+202)38351995 - Fax: (+202)38352422   ت : ٣٨٣٥١٩٩٥ (٢٠٢+)   فاكس : ٣٨٣٥٢٤٢٢ (٢٠٢+)
Factory: Borge El Arab - 4th Industrial District - No. 9-10 Block30-Alexandria-Egypt   المصنع:الإسكندرية: مدينة برج العرب الجديدة، المنطقة الصناعية الرابعة، قطعة رقم ٩-١٠ بلوك٣٠
www.perlite.com.eg   info@perlite.com.eg

103

B.3 Pumice Data Sheet

FROEHLING & ROBERTSON, INC.

Engineering Stability Since 1881

3015 Dumbarton Road
Richmond, Virginia 23228-5831
T 804.264.2701 I F 804.264.3549

September 26, 2013

PUMICE LIGHTWEIGHT AGGREGATE CRETIFICATION TEST REPORT

PROJECT NO.:   60R-0206
CONTROL NO.:   60-14-117603
CLIENT: Allied Concrete Products
                                  3900 Shannon Street
                                  Chesapeake, Virginia 23324
                                  Attn: Mr. Peter W. Schmidt
PROJECT: Aggregate Certification- Pumice
STANDARDS: ASTM C330-09, AASHTO M 195-06, and UL 618

PHYSICAL PROPERTIES

TEST	RESULTS	ASTM C330 SPECIFICATIONS
Specific Gravity: C127	1.12	---
Absorption, %: C127	18.0	---
Organic Impurities, Color: C40	No Change (0)	<3
Clay Lumps, %: C142	0.3	≤2
Loss on Ignition, %: C618	0.1	<5
Popouts: C151	None	None
Dry Loose Unit Wt., lbs./ft^3 (kg/m^3): C29	53.1 (887)	<70 (1,120)
Dry Rodded Unit Wt., lbs./ft^3 (kg/m^3): C29	56.9 (950)	---
Shrinkage @ 28 Days, %: C157	0.04	≤0.07
Stain Test, Index: C641	20 (No Stain)	<60

The above test results meet the requirements of ASTM C330-09, AASHTO M195-04 and UL 618 for fine aggregate with the exception of the amount passing the #16 sieve.

B.4 Admixture Data Sheet

◻◼ BASF

The Chemical Company

MasterRheobuild® 850 (Formerly known as Rheobuild 850)

High range, water-reducing superplasticiser for rheoplastic concretes

DESCRIPTION OF PRODUCT

MasterRheobuild 850 is formulated from synthetic polymers specially designed to impart rheoplastic qualities to concrete.

A rheoplastic concrete is a fluid concrete with a slump of at least 200mm, easily flowing, but at the same time free from segregation and having the same w/c ratio as that of a low slump concrete (25mm) without admixture.

MasterRheobuild 850 is chloride-free.

ADVANTAGES

MasterRheobuild 850 considerably improves the properties of fresh and hardened concrete.

PRIMARY USES

- Microsilica concrete
- Mass concrete pours
- Ready-mixed concrete
- Long-distance transport
- Pumped concrete
- Casting in hot climates

TO OBTAIN

- Reduced thermal peaks
- High workability for longer periods
- Lower pumping pressure
- Delayed setting with longer workability
- Higher ultimate strengths
- Reduced permeability
- Improved durability

COMPATIBILITY

MasterRheobuild 850 is compatible with all cements and most air-entraining agents meeting the ASTM standards.

The addition of MasterRheobuild 850 and Master-Air 111 (air-entraining agent) to concrete is recommended where it is required to withstand freezing and thawing cycles

PACKAGING

MasterRheobuild 850 is available in 1000 ltr.

TYPICAL PROPERTIES

Colour:	Dark brown liquid
Specific gravity:	1.21
Air-entrainment:	Maximum 1%
Chloride content:	Nil to BS 5075
Nitrate content:	Nil
Freezing point:	0°C; can be reconstituted if stirred after thawing

STANDARDS

ASTM C-494 Type B, D and G

DOSAGE

Optimum dosage of MasterRheobuild 850 should be determined in trial mixes. As a guide, the following dosages are recommended as a starting point for any trial: in normal concrete, a dosage of between 0.8-2ltr/100kg of cement; in high performance microsilica concrete, a dosage of between 1.5-3ltr/100kg of cement. Dependent upon mix requirement, it is possible to use a higher dosage of MasterRheobuild 850 without causing any adverse effects upon the concrete. Please consult BASF's Technical Services Department for further information.

DISPENSING

MasterRheobuild 850 is a ready-to-use liquid, which is dispensed into the concrete together with mixing water. The plasticising effect, or water reduction, is higher if the admixture is added to the concrete after 50-70% of the mixing water has been added. The addition of MasterRheobuild 850 to dry aggregate or cement is not recommended. Automatic dispensers are available.

WORKABILITY

MasterRheobuild 850 ensures that rheoplastic concrete remains workable in excess of 3 hours at +20°C.

MASTER®
»BUILDERS·
SOLUTIONS

MasterRheobuild® 850 (Formerly known as Rheobuild 850)

Workability loss is dependent on temperature, on the type of cement, the nature of aggregates, the method of transport and initial workability. It is strongly recommended that concrete should be properly cured particularly in hot and dry climates.

STORAGE

MasterRheobuild 850 must be stored where temperatures do not drop below +5°C. If product has frozen, thaw and agitate until completely reconstituted. Store under cover, out of direct sunlight and protect from extremes of temperature.

Failure to comply with the recommended storage conditions may result in premature deterioration of the product or packaging. For specific storage advice, consult BASF's Technical Services Department.

SHELF LIFE

Up to 24 months if stored according to manufacturer's instructions in unopened containers.

SAFETY PRECAUTIONS

MasterRheobuild 850 is not a fire or health hazard. Spillages should be washed down immediately with cold water.

For further information, refer to the material safety data sheet.

NOTE

Field service, where provided, does not constitute supervisory responsibility. For additional information, contact your local BASF representative.

BASF reserves the right to have the true cause of any difficulty determined by accepted test methods.

QUALITY STATEMENT

All products manufactured by BASF Egypt, or imported from BASF affiliate companies world-wide, are manufactured to procedures certified to conform to the quality, environment, health & safety management systems described in the ISO 9001:2008, ISO 14001:2004 & OHSAS 18001:2007 standards.

* Properties listed are based on laboratory controlled tests.

® = Registered trademark of the BASF-Group in many countries

B.5 Curing Compound Data Sheet

◻ ▪ BASF

The Chemical Company

MasterKure® 181

(formerly MASTERKURE 181)

Acrylic resin based, multi-role curing, sealing and protective membrane

DESCRIPTION

MasterKure 181 is a non-degrading, membrane-forming liquid based on specially formulated acrylic resin suitable for curing newly placed or freshly deshuttered concrete; assists in the retention of water during hydration. The resultant film retains sufficient moisture in the concrete to ensure full hydration of the cement; essential for optimum strength development. The cured concrete is typically harder and exhibits a dust free surface with a reduced incidence of drying shrinkage cracks. Additionally, the membrane acts as a primer system for many subsequent surface finishes that do not rely on penetration for substrate bond. When applied to floors, the **MasterKure 181** seals and dustproof the surface, eliminating the primary source of abrasion and enhancing durability.

MasterKure 181 is available as a clear translucent liquid and white solar reflective version.

RECOMMENDED USES

As a more effective and economical alternative to separate curing and priming/sealing regimes. Suitable for use on all concrete surfaces.

- Surfaces subject to finishing treatments.
- Economical enhancement of concrete flatwork.
- In high-rise construction to eliminate the requirement for water.

FEATURES AND BENEFITS

- Improves moisture retention in concrete
- Prevents rapid water evaporation
- Sealer & dustproofer
- Good abrasion resistance – long protection
- Reduces drying shrinkage
- Reduces the incidence of hairline cracks
- High curing efficiency
- Available in Solar reflective grade
- Non – degrading – no removal required
- Act as primer for protective coatings & bitumen

PERFORMANCE TEST DATA

Appearance	: Clear/white liquid
Specific gravity Clear	: 0.82 ± 0.01 at 25° C

White	: 0.855 ±0.01 at 25° C
Flash point	: 30°C
Dry film appearance	:Clear or white
Loss of Water (ASTM C156)	: < 0.55 kg /m²
Drying time (ASTM C309)	: 45 mins at 25°C

TEST CERTIFICATION/APPROVALS

- Clear version - ASTM C309 Type I Class B
- White version - ASTM C309 Type II Class B

COVERAGE

The recommended rate of application is 4-6 square metres per litre. This corresponds to that at which **MasterKure 181** has been tested, and at which it attains the claimed degree of curing efficiency. In favourable conditions such as shaded interior surfaces, adequate curing can be achieved with extended coverage rates.

When using **MasterKure 181** for floor areas where maximum chemical and wear resistance is required, it is recommended that a further coat be applied after 24 hours.

In place of the above recommendations, the rates of cover stipulated in a specification should at all times be observed.

APPLICATION

Surface Preparation

NEWLY PLACED CONCRETE:

Surface must be sound and properly finished. Surface is ready for application of **MasterKure 181**, when damp, but not wet, and it can no longer be marred by foot traffic.

NEWLY CURED BARE CONCRETE:

Level any gouges. Remove all dirt, dust, oil, grease, asphalt, and foreign matter. Clean with caustics and detergents as required. Citrus degreaser is excellent for removing oil stains and many curing compounds. Rinse thoroughly and allow to dry. Apply **MasterKure 181** to damp but not wet surfaces.

MASTER® ≫BUILDERS SOLUTIONS

BASF
The Chemical Company

MasterKure® 181
(formerly MASTERKURE 181)

AGED CONCRETE:

Restore surface to soundness by patching, grouting, and filling cracks or holes. Surface must also be free of any dust, dirt, and other foreign matter. Use power tools or strippers to remove any incompatible sealers or coatings. Clean as required, following procedure under "Newly cured bared concrete".

Application

Stir **MasterKure 181** thoroughly before using. Apply a continuous, uniform film by low-pressure spray, short nap roller or brush.

Application not recommended when surface temperature exceeds 40°C

Subsequent surface finishes

The resin in **MasterKure 181** ensures that bond is maintained with adhesives used for installing tiles, and other floor coverings. **MasterKure 181** will act as a primer for paint systems and will enable most surface treatments to progress with minimal delay.

Typical surface treatments that will bond to surfaces with **MasterKure 181** are:

*   Water based emulsion paints containing PVA, PVC and acrylic co-polymers
*   Tile adhesives based on the above polymers
*   Bituminous emulsions and solutions.
*   Thin section polymer modified cementitious systems.
*   Polyurethane resin system
*   Polysulphide systems
*   Epoxy resin compositions which do not rely on penetration for substrate bond.

For further information regarding compatibility of **MasterKure 181**, contact your local BASF Representative.

Cleaning

Use CLEANING SOLVENT NO. 2 to clean rollers and spray equipment before **MasterKure 181**

become dry. Any excess cured material will have to be mechanically removed.

SUGGESTED SPECIFICATION

The non-degrading membrane forming curing & sealing compound shall be **MasterKure 181**, acrylic resin based formulation. The product shall comply with ASTM C 309 Class B. The product shall exhibit water loss not more then 0.55 kg/m^2 in 72 hours when tested as per ASTM C156. The product shall form non-degrading abrasion resistance film which shall also exhibit capability as primer for subsequent protective coatings or bituminous overlays.

PACKAGING

MasterKure 181 is available in 5 & 20 litre packs.

STORAGE /SHELF LIFE

MasterKure 181 must be stored where temperatures do not drop below +5°C. Store under cover, out of direct sunlight and protect from extremes of temperature.

Shelf life is12 months when stored as above.

Failure to comply with the recommended storage conditions may result in premature deterioration of the product or packaging. For specific storage advice consult your local BASF representative.

PRECAUTIONS

As with all chemical products, care should be taken during use and storage to avoid contact with eyes, mouth, skin and foodstuffs (which can also be tainted with vapour until product fully cured or dried). Treat splashes to eyes and skin immediately. If accidentally ingested, seek immediate medical attention. Keep away from children and animals. Reseal containers after use. Do not reuse containers for storage of consumable item. For further information refer to the material safety data sheet. MSDS available on demand or on BASF construction chemicals web site.

TDS Ref. no.: **Masterkrxx181/01/0313**